Cultural Transmission of Lithic Artefact Traditions: an Experimental Approach

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I, Stuart Page confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

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Abstract

Experimental methods for exploring the idea that cultural variation can be explained as part of a process analogous to that of biological evolution have been used in psychology to examine how human copying error effects the transmission of simple artefact form. Applying these methods in an archaeological framework, this study is the first of its kind to develop a programme of transmission chain experiments exploring different aspects of skill, social interaction and copying error and their effect on the evolution of artefact form in two different Palaeolithic technologies: blade production and Acheulean handaxe manufacture.

In the blade replication experiment, form trajectories produced by two different levels of skill could be distinguished, with the more skilled knappers choosing to pass on the best match for blade length, in preference to shape or ridge pattern. In the Acheulean experiments, in conditions where loss of refinement features was expected, a surprising result was the consistent survival of planform symmetry. Where maintaining refinement was the focus of the teaching condition, thinning was achieved to a high level, without loss of size, but paradoxically, symmetry survived less well. It was concluded that the level of knapping skill, in all transmission scenarios, was a key factor in the formation of attribute variation.

Difficulty experienced when aligning results from experimentally produced transmission biases with archaeological assemblages, demonstrated that in reality, cultural transmission was likely a fluid process where differing biases occurred at different times within the lifecycle of each Palaeolithic group. The specific signal provided by archaeological assemblages is likely to reflect the skill level and position of the knappers within that cycle, rather than the existence of a singular type of transmission bias. This approach provides new and enhanced ideas on the nature of cultural transmission in the Middle Pleistocene groups of *Homo heidelbergensis*, reinforcing the importance of teaching in the culture evolutionary process.

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Acknowledgements

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To my supervisors, Professor James Steele and Doctor Ignacio de la Torre, the greatest of thanks for all the guidance you have given me over the past 3 years. To James, special thanks for selecting me to work on what has been an excellent project. Your help has always been fantastic and our regular meetings prove that Stockholm syndrome is indeed, a legitimate phenomenon.

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Chapter 1.

Introduction

1.1 Background to the research problem and original contribution of proposed research

Historically, the causes and levels of variation in Palaeolithic artefact form have been considered from the differing viewpoints of ecology (Clark, 1994), cultural identity (Bordes, 1961a), function (Binford, 1973), raw material (Jones, 1979), reduction stage (Dibble, 1995), bio-mechanics (Bril *et al,* 2010) and cognitive evolution (Stout & Chaminade, 2007; Wynn, 1979). Experimental stone knapping has enabled the exploration of some of these causes of artefact variation. However, it has not yet been used to systematically explore the social transmission of knapping skill. The wider aim of this research programme, consisting of four separate but interlinked experiments, is to more securely place the cultural evolution of lithic artefact form, in a Darwinian framework. Viewed in a micro-evolutionary context, this means skill, transmission and copying error, both conscious and subliminal producers of artefact or attribute difference, will be analogous to genetic variation (Mesoudi, 2011). Differing forms of cultural transmission, created under laboratory conditions and the variable effects those conditions have on attribute reproduction, will provide the analogy for competition, whilst the mechanism for transmission and inheritance of variation in lithic artefact form (i.e. 'descent with modification') will be created by using multiple generations of flint knappers, working in transmission chains (TCs).

Although it is impossible to recreate the differing conditions faced by the many thousands of generations of early *Homo,* together with the selective and functional constraints that tool manufacture would have been subject to throughout the Palaeolithic, laboratory based TCs were adapted in this research, to explore specific issues in the production and cultural transmission of lithic forms such as the Acheulean handaxe. In this context, TC theory possesses the ability to isolate specific aspects of the culture evolutionary dynamic that likely formed part of the tool production process. In this series of experiments, knapping skill and the transmission of that skill, in a manner that was able to constrain artefact form, as a function of a culturally enforced group norms or because of functional necessity, was seen as a way of explaining hominin behaviour and the presence of two specific lithic phenomena in the archaeological record. Those were, firstly, the standardised nature of Upper Palaeolithic blade based technology, where regulation of variation was necessary due to the functional constraints of composite tool forms such as hafting (Barham, 2013), and secondly, attribute variation that was constrained within the forms of a conservative tool form, in this case the Acheulean handaxe, that remained fundamentally unchanged for over a million years.

Multi-generational transmission chains have been investigated in experimental psychology, to explore the evolution of simple artefact form (Caldwell & Millen, 2008; Mesoudi, 2008), and could provide an experimental framework for the examination of how social transmission strategies, skill and copying errors influenced the evolution of prehistoric technologies. To date, no experimental archaeological research has been conducted on the effects of multi-generational copying of lithic artefact forms. The objective of this research is to develop, test and implement experimental transmission chain protocols (TCPs) for studying the effect on the multi-generational transmission of lithic artefact form of innate perceptual and motor biases, and of the differing learning and teaching strategies that human groups have devised to manage their effects. This series of experiments will be the first to integrate elements of transmission chain methodology developed in experimental psychology, with existing methods of experimental archaeology. It will examine the hypothesis that variation over time, in lithic form, is a product of socially generated copying biases that, to differing degrees, determine the direction of cultural evolution. The expectations of such a hypothesis will be compared against those generated from a 'null model' in which artefact form is expected to change due only to random copying error.

The research conducted for this PhD was part of a larger Leverhulme Trust funded project entitled 'Learning to be Human', involving complementary strands of research conducted by Professor Bruce Bradley's (BB), experimental archaeology research group at the University of Exeter (UK) and by Dr Dietrich Stout (now of Emory University, USA) at the UCL Functional Imaging Laboratory in London. The University of Exeter research strand focused on the experimental reproduction of skill acquisition, related to reproducing different Palaeolithic technologies. The Emory University strand focused on fMRI brain scans, designed to isolate the specific areas of the brain responsible for knapping those different lithic technologies, with the aim of relating this to hominin cognition and brain development throughout the Lower and Middle Palaeolithic. With regard to the cultural evolution of artefact form, the transmission chains on which the research in this thesis are based were constructed using members of the flint knapping cohorts recruited and trained at Exeter, by BB (a master-knapper himself) as part of the wider project. One of the challenges to such research is having enough competent knappers to build effective TCs. As the wider research programme of the 'Learning to be Human' project trained sixteen knappers (between 18 and 54 years old at project commencement), including two knappers of higher skill levels, it provided a pool of varied but appropriately skilled participants. Drawing from this pool allowed the construction of the bespoke transmission chain methodology required to undertake this unique research project. With subject cohorts of differing skill levels, ranging from experienced to novice, the mechanics of transmission chain theory could then be varied depending on the criteria of each experiment.

1.2 Research aims and experimental design

As stated in section 1.1, the broad objective of this thesis is centred on the exploration of cultural evolution and its effect on lithic artefact form as it is transmitted between multiple generations of knappers. The aim here is to offer new or complimentary explanations to specific (and longstanding) Palaeolithic research questions, such as accounting for attribute variation (temporal and spatial), but within the constrained tool form of the Acheulean handaxe. This is addressed by developing a methodology/research design with the following three aims.

- The adaptation and development of TC theory to create a series of TC experiments designed to replicate likely modes of transmission in the Palaeolithic. Those modes or types of transmission, as modelled by each individual TC would be discrete in nature, representing a pure version of the specified transmission bias, with each knapping generation not effected by differing types of bias or instruction.

- To develop a system of measurement and statistical analysis capable of effectively capturing the variation created by the differing forms of cultural transmission, represented by each TC.

- To be able to compare the levels of variation captured by each of the experimental TC assemblages with that produced from archaeological assemblages, measured and analysed according to the same methodologies. The ultimate objective here is to enable judgements on the type of transmission technique used in different Palaeolithic assemblages, according to the types and levels of variation they demonstrate, compared to the levels obtained from the experimental examples produced by each TC.

It should be noted that this thesis does not propose that differentials in knapping skill and type of transmission bias are responsible for all variation in lithic output. It is important to reiterate that the TC experiments conducted here represent idealised forms of transmission, where no selective pressure is brought to bear, other than trying to produce an exact copy of the target form presented by the previous knapping generation. This protocol does not take account of the fact that variation in tools recovered from the archaeological record may have been created by different levels of curation (such as resharpening), before their eventual disposal (see Chapter 5). Form differences in archaeological tool types may also be attributed to functional requirements dictated by the nature of specific tasks, perhaps most famously highlighted by Lewis Binford and his account of Mousterian toolkit variability (Binford & Binford 1966; Binford 1973). In terms of handaxe variability, for example, small handaxes (or blades) were likely more functionally efficient at performing certain tasks than larger handaxes, which could help explain variation in different groups of archaeological handaxe size, such as the small and large groups found at Kilombe (Gowlett 2005), discussed more fully in Chapter 5. With this in mind, when comparing levels of experimentally created variation with that identified from archaeological forms, assumptions should be made about whether each tool type is regarded as fundamentally the same (albeit from an etic perspective). It should also be noted that where functional efficacy appears to be guiding certain aspects of artefact form, it is (as discussed in Chapter 2) likely a specific form of transmission bias that maintains the repeated creation of that form (on a multi-generational basis), by the way that teaching and instruction occurs. It is this culturally generated process that minimises the effects of drift, related to skill or perceptual limitations, allowing the required pattern of functional attributes to be recreated, in the most efficient manner possible.

In the context of understanding variation in Palaeolithic tool form, it is perhaps difficult to neatly divide the traditional dichotomy of form and function, which is so often used as the basis to decoding and forming our understanding of humanly constructed objects. Artefacts such as the Acheulean handaxe are multivariate objects and although creation of form undoubtedly occurred through the knapping and management of differing attributes, such as length, width, and thickness, the eventual form would also have been governed by some basic functional requirements (Gowlett, 2006). This did not create a standardised tool form with strict parameters, but did likely require what Isaac (1977) identified as a tool form that would achieve its functional requirements within broad target zones of design. Within those zones, the archaeological record demonstrates variation, some of which will not be due to form or function, but to failed or partially completed handaxes (or other tool forms), as noted by Davidson & Noble (1993). Such variation is an inevitable reflection of knapping skill and or human perceptual limitation, factors that are often undervalued as major dynamics in the creation of artefact variation.

The concept of achieving a functionally efficient tool within a design zone, or one that illustrates accepted ranges of variation from a recognised standardised form offers a workable solution to accounting for artefact variation (and one that is discussed more fully in Chapter 5). However, it does not explain how that concept would have been taught or communicated, or the differing levels of variation likely created by specific types of transmission technique – which is a key objective of this research. The copying of a target form, as closely as possible, as opposed to creating an artefact that varies (within a zone) but is still functionally viable, is the purest way to understand variation generated by skill or perceptual limitation. In this respect, the basic experimental purpose of each type of transmission chain is to provide a controlled setting in which to observe the cultural transmission of an artefact and the evolution of its form as it is copied by each succeeding member of the chain or 'copying generation' (Mesoudi, 2008; Mesoudi, 2010). This process can then continue for as many iterations as are deemed necessary or are logistically practical. All chain types are designed to represent successive micro-generations and provide insight on differing methods or types of transmission through those generations. The three main options for multi-generational transmission chain structure, variants of which were used in this project (and explained in more detail in the experimental design section) are as follows.

- The single member linear chain
- The closed group chain
- The open group or replacement chain

As the production of lithic tools is a reductive technology (Schillinger *et al,* 2014), requiring relatively high levels of knowledge and skill, it is expected that most *single member chains* (the TC type used in Experiment 1 and 2), dependent on copying instructions, will require no more than 8 generations of single knappers for significant changes in form to occur between the initial 'model' or base target form and that produced by the final chain member. The *single member TC* was modified for the third experiment of this thesis, to represent a condition where the new knapper in each generation was provided with instruction by the same expert tutor or cultural parent for the duration of the TC. A *closed group chain* is defined as one where group members for each generation remain unchanged; this particular TC design (or TCP) was not used for the experiments on which this thesis is based. An *open group* or *replacement chain* works on the basis that for each successive generation, one or more members of the group leaves and are replaced by new members (for example, an experienced member may be replaced by a novice). With open group chains (Experiment 4 in this project), the groups that comprise each generation will consist of four people. Three of those people will be more expert knappers taking on an instructional role and will remain the same for each generation of the TC. The fourth person will be a knapper of lesser ability who will be replaced in each generation by a new knapper of similar ability. The high degree of skill required to knap stone tools effectively means a fully rotational open chain of more than 8 generations is not achievable, due to the limited number of expert knappers available to fulfil a teaching role and also the number of knappers available and trained to an intermediate level.

Despite experimental limitations imposed by the time required to acquire and learn effective knapping skill, the work is still able to shed light on how innate perceptual discrimination, acquired skill level and differing techniques of transmission can each affect the evolution of artefact form. Of the four separate TC experiments, the first focuses on blade production, the remaining three on Acheulean handaxe manufacture. The rationale for experimentation with the transmission of handaxe form was driven by the desire to apply transmission chain theory to what has become a longstanding issue in Palaeolithic archaeology, that of accounting for variation in handaxe form but variation that existed within the confines of a conservative tool form that remained fundamentally unchanged for over a million years. Each experiment will be designed to explore different aspects of the reproduction of lithic form, as it passes through and is copied by multiple generations of knappers. In particular, the focus will be on the following research questions:

- What is the effect on the evolution of lithic artefact form of differences in skill level?

- Can humans visually discriminate between artefacts whose dimensions vary within a given range (for example 3%-5% of any linear dimension) without the aid of external measures or yardsticks? Any innate limitations in discriminative ability of this kind would, if left unchecked along a transmission chain, lead to cumulative and unintended drift over time, in artefact form.

- What is the cumulative effect on artefact form of multi-generational copying where initial target forms are typologically different (etically, or as defined by archaeologists) but fall within the same broad artefact descriptor, for example, are ovate handaxes more likely to evolve and drift into point-form handaxes or vice-versa?

- How does group composition within each TC and each generation (range of variation in skill level and nature of communication dynamic) affect the evolution of lithic artefact form? The effect of the presence of an expert knapper or of group dynamics on the artefacts produced by those with lower skill levels were explored in single member chains and open groups respectively. For example, is form more strongly conserved across copying generations when communication is 'one-to-one' or 'many-to-one'? Such experiments were designed to shed light on the way in which teaching or collaborative learning modulates any underlying tendency for artefact form to either remain constant or exhibit variation.

1.3 Thesis structure and focus of transmission chain experiments

Chapter 2 is divided into two main sections, the first of which reviews and discusses the background to experimental lithic archaeology with specific focus on studies concerned with acquiring and evaluating knapping skill. The second part of the chapter explains the theory of cultural transmission chains with specific focus on experiments using archaeological traditions as their reference point. It introduces the concepts of skill acquisition, stylistic variation and random drift in the context of TC theory and highlights methodological problems that need to be overcome for TC theory to function effectively in an experimental archaeological context. Chapter 3 is devoted to materials and methodological innovations uniquely developed by the 'Learning to be Human' project, to allow lithic transmission chains to function effectively. It focuses on the creation of a homogenous raw material from which to create standardised preform cores; on procedures for training knappers to the appropriate level in the type of lithic technology used in each experiment; on skill assessment programmes to ascertain whether the relevant skill level had been reached and on statistical techniques developed to analyse and compare variation on an inter and intra-assemblage basis. Chapter 4 describes the first TC experiment, which focuses purely on the effect of differing skill level on variation within two separate transmission chains. The chosen technology for the first experiment was blade production and to some extent, it represented an initial trial of the methodology to be used in the rest of the programme. Chapter 4 also presents the results and statistical analysis of data gathered in Experiment 1.

Chapter 5 discusses previous research and issues relevant to variation found in the manufacture of archaeological Acheulean handaxes, traditionally ascribed to either raw material variation or reduction strategy. It is intended to provide background explaining research into two main areas: firstly, issues surrounding the distinction between ovate and point form handaxes, that is, over multiple generations of copying, does one form drift into the other, or, are they the distinct, emic, cultural forms defined by Roe (1968)? Secondly, it will discuss issues pertaining to variation created by demographic factors and different forms of transmission or copying bias that may have worked in tandem with unstable population levels, in small hominin groups. These two areas of theory form the reasoning behind the remainder of the research programme and the exploration of factors likely to create differing levels of variation, within a conservative tool form. To that end, Chapter 6 covers Experiment 2 and focuses on the evolution of form as a result of 'guided variation' (Boyd & Richerson, 1985) or the base line of variation created by the trial and error reproduction of handaxes by knappers not constrained by external forms of control. Chapter 7 covers Experiment 3 and introduces the concept of vertical transmission, which in this context means the instruction of each knapping generation, on a one-to-one basis by a cultural parent. Chapter 8, covering Experiment 4, explores levels of variation produced where cultural transmission takes the form of oblique, many-to-one instruction from senior peers, operating in open group transmission chains. A comparison of the results from the differing transmission biases used in Experiments 2 – 4 is presented in Chapter 9. This forms the basis of a discussion suggesting likely reasons for stasis and variation within handaxe form. To bring the experimental results into immediate relief with the archaeological record, there is also comparison with archaeological Acheulean handaxe assemblages from the Middle Pleistocene. It is against this backdrop that discussion on the types of cultural transmission likely prevalent amongst hominin groups of the Middle Pleistocene occurs.

The thesis concludes by highlighting the methodological problems solved to achieve its objectives, such as the development of a standardised porcelain core technology, to neutralise the problem of heterogeneous raw material, so often a barrier to providing a neutral starting point in experimental lithic archaeology. Following this, it summarises the main findings for blade and handaxe experiments, which demonstrate the ability of differential skill levels and cultural transmission biases to change the trajectory of artefact form, over multiple generations of copying. Conversely, it goes on to highlight the issue that experimentally created cultural or socially produced bias, such as many-to-one instruction, can also be used to restrain the level and type of variation (that occurred in cases where copying took place in unregulated TCPs). It also concludes the issue that there is some likelihood that variation in archaeological assemblages of handaxes can be aligned with that produced in experimentally produced TCPs, suggesting that reconstruction of Palaeolithic methods of cultural transmission is possible, and in conjunction with demographic theory of early hominin populations, can be used to provide new hypotheses to explain issues such as the long-term constrained form of the Acheulean handaxe. Comparison is made to archaeological handaxe assemblages from the Middle Pleistocene sites of Boxgrove, Cuxton and Tabun, with specific focus on explaining the consistency of artefact form at Boxgrove and the likelihood that this was produced by a positive and structured form of cultural transmission.

Finally, it discusses the limitations of the research design and provides suggestions for the direction of future research in lithic experimentation, using transmission chain theory. The raw data for Experiments 1 – 4, together with the comparative archaeological handaxe data is supplied on a CD-ROM and presented in Appendix 10.

Chapter 2.

Theoretical development of experimental work in lithic archaeology related to knapping and reproduction of artefact form and transmission chain theory

2.1.1 Introduction

This study is concerned with a range of issues impacting on the cultural transmission of variation in lithic artefact form. This particular chapter concerns the trajectory of two disciplines, lithic experimentation and transmission chain theory, that have, to date, grown independently of one another. On that basis, the first part of the chapter reviews the background and theoretical issues that have framed the development of experimental lithic archaeology, whilst focusing on studies that shed light on factors affecting skill in the knapping process and cultural transmission of techniques and stylistic attributes. The second part of the chapter explains the use of transmission chain theory in psychological experimentation and how it can be used and adapted to explore issues relevant to the cultural transmission of change or stasis in lithic artefact form. Although the advance of time and technology are relevant in each of the above fields, both chapter sections are presented thematically (as opposed to chronologically). This is to enable discussion of the main issues surrounding both disciplines with a focus on how to combine them, in the experimental exploration of how cultural transmission can affect the evolution of and degree of variation present in an archaeologically attested craft technique such as flint knapping.

It could be argued the beginnings of experimental archaeology in lithic technology began with Sir John Evans and the account of his own experience of flake removal, to reproduce the form of an Acheulean handaxe (Evans, 1860: 293). The primary aim of Evans and his contemporaries e.g. Nilsson (1868), Steenstrup & Lubbock (1867), Skertchly (1879), was to prove lithic artefacts could be reproduced by hand and were the work of humankind and not nature.

To this end, Evans gave the first recorded public demonstration of flint-knapping to the International Congress of Prehistoric Archaeology in Norwich, in 1866 (Johnson, 1978: 337). By helping to establish human authorship of knapped artefacts, and their existence beyond the prevailing biblical chronology prevalent in the Antiquarian era, Evans highlighted and conducted experimentation, between 1860 and 1872, in most areas that continue to frame the agenda of lithic experimentation in the current day. This section, where possible, will be structured under headings formed by taking the work of Evans and using the themes he developed as a baseline from which to discuss the main areas in experimental lithic research. The impact of each area on cultural transmission and the resultant technical and stylistic variation will be discussed by using case studies presented by contemporary scholars, working in each specific area.

2.1.2 The bio-mechanics of flake removal

The variables involved in single flake removal, the most basic unit of knapping (Schick & Toth, 2006: 4) are described in Evans (1872: 17-19), where a precise blow delivered to a platform with an exterior angle of 45° will detach a flake showing a bulb of percussion and feathered termination. Evans goes on to discuss the level of skill required to execute this action by stating the difficulty required to strike the core accurately, in the correct place and with an amount of force appropriate to detach the desired flake without shattering it, or bruising the core and crushing the platform. This was an early statement on the mechanics of knapping and formed the basis of subsequent studies by many scholars; see Johnson (1978) for an extensive list. Although the inherent difficulty involved in knapping was repeatedly revealed by such studies and illustrated by contemporary master-knappers such as Crabtree, Tixier, Bradley and Callahan, it was perhaps Bordes who best summed up the undefined nature of the kinetics involved in creating stylistic difference in the knapping process, in the phrase: “I feel them more than I see them.” (Bordes’ comment to Johnson) (Johnson, 1978: 359).

Technological advance has provided more recent studies with the ability to isolate the inter-dependent nature of the component actions involved in knapping; a process focused on identifying the bio-mechanical causes of variation in stylistic attributes. By using moulded glass cores to create a consistent and homogenous raw material, and apparatus that pneumatically controlled percussive forces (Figure 2.1), Dibble & Rezek (2009) were able to hold constant all mechanical factors involved in the knapping process, whilst altering single variables. Employing Newton's second law, where velocity is defined as speed in a given direction and a change in velocity is acceleration, such specific levels of manipulation facilitated the discovery that, after sufficient force (i.e. mass x acceleration) had been reached, further increases, whilst holding all other variables stable, made no difference to the size of flake removed. However, the same force used in conjunction with either differing exterior platform angle, angle of blow or platform depth would produce respectively different outcomes, resulting in flakes of different length and or width. At the most basic level of bio-mechanic action required to produce single flake removals, Dibble & Rezek (2009) highlighted the importance of ability to control platform morphology and the level of skill required to manage such attributes.

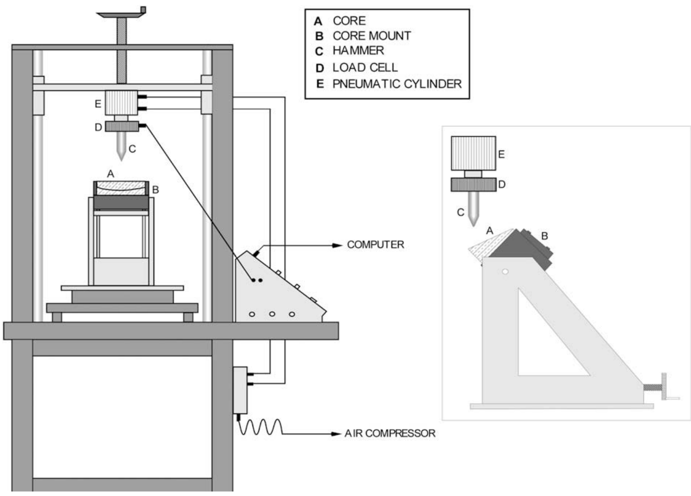


Figure 2.1. Schematic of pneumatic flaking machinery showing how single variables e.g. velocity or platform angle can be altered, whilst holding all other components of the flaking process constant, to ascertain the effect on flake form.
(Dibble & Rezek, 2009: Fig 3).

Physical manipulation of these factors is seen by Bril *et al* (2010: 825) as the ability to solve problems presented by the differing dynamics and inter-related aspects of environmental factors; a scenario regulated by the levels of sensory-motor skill possessed by the individual knapper. In this sense, the position of Bril *et al* (2010) rests in ecological psychology and to that end they conduct a series of three experiments where a cohort of novice, intermediate and expert knappers are required to produce flakes of differing dimensions with differing weights of hammerstone. To place these actions in the Newtonian framework established by the work of Dibble and Rezek (2009), the actions of each knapper were monitored using a magnetic tracking system to record the swing distance, point of impact and level of kinetic energy employed, in response to changing task parameters and differing weight of hammerstone. In this respect, distance of swing directly affects the velocity of each hammerstone weight and the force or level of kinetic energy with which it strikes the core. In all tasks and for all groups except those performed by the expert knappers, the level of kinetic energy invested in the strike and the distance of swing increased especially when detaching both small and large flakes with a small hammerstone. This is a function of their inability to control the other inter-dependent parameters i.e. appropriate adjustment of trajectory and bodily movement or position. In this respect, although flake removal is the result of a fluid sequence of action, each component action of that sequence defines the degree to which the other co-components should be varied by the knapper. In this sense, their relationships are nested. Expert knappers possess or have developed a physical understanding of the nested and interconnected relationships that exist between the functional parameters, control parameters and regulatory parameters required by the detachment process (Figure 2.2). This allows them to produce specified flake sizes with the most efficient trade-off between the demands of precision and the required level of kinetic energy. For example, if hammerstone mass decreases by half, correcting for the loss is not simply rectified by doubling the velocity of the strike. When responding to goal-directed actions, Bril *et al* (2010) state it is the degree of motor-management created by repeated ‘bodily practice’ that permits the level of knapping skill to increase from novice – to intermediate – to expert, especially when the external or control factors such as hammerstone mass, are changing on a rapid basis.

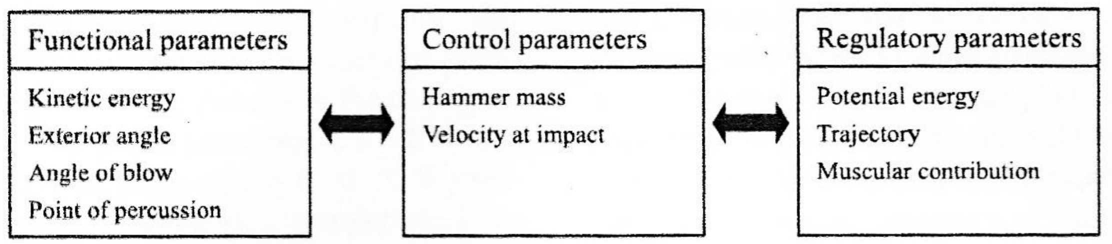


Figure 2.2. A three layer knapping system showing the interconnected nature of the parameters involved in flake detachment. In this sense, the *functional parameters* are the individual but interdependent requirements necessary for flake detachment. *Control* and *regulatory parameters* impact on the *functional parameters* and are governed by the varying actions or level of control employed by each individual knapper on each individual parameter.
(Bril *et al,* 2010: Fig 2).

Although Bril *et al* (2010) explored the effect of differential levels of knapping skill on flake detachment, by varying the control parameter of hammerstone mass, they failed to fine tune the approach by also controlling for raw material effectively. The cores used were described only as “broadly similar … weighing between 2 and 3 kg .. and were crudely prepared by an expert knapper” (Bril *et al*, 2010: 828). This macro-level approach to controlling for raw material homogeneity was also employed by Nonaka *et al* (2010), who further developed the relevance of skill related to controlling the mechanics of conchoidal fracture, by demonstrating only ‘expert’ knappers were able to accurately remove specific flake outlines marked on what they described as standardised cores - despite acknowledging their irregular nature. In this respect, the cores, although described as standardised, still possessed the capacity to be different enough in shape, weight and inclusion level to create variation that was not a product of skill differential but likely due to the vagaries of heterogeneous raw material. Despite this weakness in approach to raw materials, the exercise demonstrated the level of control expert knappers were able to bring to bear, by accurately manipulating each individual parameter, as related to the other nested and inter-dependent variables. As well as detaching predefined flake outlines, the more skilled knappers were also able to produce an organised debitage, meaning the control they exercised in removing single flakes enabled them to manage the core reduction process, so each individual removal set-up the core for effective subsequent removals. This is an outcome reinforcing the notion that skill development requires a repetitive and regular learning experience. Nonaka *et al* (2010: 164) draw an analogy comparing the organised debitage of the experts to that produced at Lokalelei 2c (Roche *et al,* 1999; Delagnes & Roche, 2005) and that of the less skilled groups to the more expedient assemblages of Lokalelei 1 or other basic Oldowan assemblages. Extending this analogy presents the idea that early differences in knapping ability such as that presented by the variation in levels of curation between the Lokalelei 1 and Lokalelei 2c assemblages, were not necessarily a linear phenomenon in an evolutionary sense. Rather than being the result of knapping by two different species or of cognitive advancement through increased brain size or reorganisation, they were more likely the result of differing levels of skill, linked to variation in the frequency of learning. Examples of skilled flake removal and organised debitage in the early Stone Age were also illustrated at Peninj (de la Torre *et al,* 2003), and in comparison with the modern experts, illustrate likely occurrences of extensive practice by early hominins and the existence of wide differentials in the level of knapping skill and the ability to manage the mechanics of conchoidal fracture, even amongst Oldowan populations of *Homo habilis*.

2.1.3 Lithic variation as a function of skill

From his early experimental work in describing the process that likely created Palaeolithic tool forms and then subsequently mastering the knapping technique required, it is clear that Evans had distinguished the difference between understanding a reduction process and possessing the skill to physically execute it. This is best illustrated in Evans (1872: 38-39), where he accurately describes the pressure flaking technique required to thin the projectile points of the North American tribes and Danish Neolithic/Bronze Age daggers, but confesses he does not have the ability to execute the required actions. Accurate descriptions of his ability to reproduce Acheulean handaxes are described in

Evans (1860: 293) and his understanding of *livre-de-beurre* and the blade industry of Pressigny are described in Evans (1866: 382).

Experimental work has tended to define lithic variation in the archaeological record as either a function of acquired skill or different levels of innate ability possessed by some but not others. Where techno-cultural form has clearly reached a zenith, as is the case in the production of late Neolithic flint daggers of southern Sweden and Denmark, Olausson (1998) raises the issue of innate skill, which she terms ability; and non-innate skill, which is an acquired phenomenon. By interviewing 197 knappers, Olausson (1998: 94) discovered that those possessing an ‘excellent’ level of knapping are fewer than would be expected if knapping skill was uniformly distributed. In this context, Olausson (1998) characterises some of those with excellent knapping skills as possessing a degree of innate ability. Although Olausson’s (1998) evidence borders on the anecdotal, her survey correlated knapping prowess with those individuals possessing high levels of artistic and spatial ability. The results of these high achievers are likened to craftsmen who are able to process and execute “complex constellations of knowledge” (Olausson, 1998: 109), which is the third level of a framework created by Wynn (1993), where the level of skill attained is beyond that achievable by a normal person not possessing high levels of innate ability.

Conversely, Finlay (2008: 68-70) considers acquisition of knapping skill to be something achievable by all and believes that many modern studies are overly focused on highly skilled knappers working in isolation, likely the exact opposite to how knapping skill was acquired for most of prehistory. Ethnographic studies such as that of Stout (2002a) and Pétrequin & Pétrequin (1993), and debitage reconstructions reported by Pigeot (1990) adequately demonstrate this by highlighting the importance of the group and the socially integrated nature of knapping. Finlay (2008) highlights other constraints of modern experimental work in its tendency to focus on extremes of ability by comparing novice with expert. To address these issues, she explores the idea of lithic technology as a means of highlighting mixed levels of ability and achievement, and suggests the concept that consistency of production is a key marker of knapping expertise.

To highlight consistency and differentiate ability levels of individual knappers, Finlay (2008) set a mixed ability cohort of six knappers, consisting of one novice with no experience, one knapper with two years' experience, one with ten years and three with over 18 years of experience, the goal of blade production (using blade blanks suitable for the production of microliths). The overall range of variation produced by attribute, for each knapping event, was recorded. Final core morphology and a blade index measuring the proportion of each assemblage that comprised suitable blade blanks was also evaluated as a key indicator of skill level. When compared against the level of expertise that was self-allocated by the participants or based on hours of knapping, Finlay (2008: 82) discovered considerable overlap and inconsistency in the quality of each assemblage produced. The knappers (B and A) with the best blade index (1^{st} and 2^{nd} respectively), on a cumulative basis, did not always achieve the highest level of complete or regularly shaped pieces (Table 2.1). Although only providing top-line summary information, Table 2.1 also shows that knapper D, technically of intermediate skill level (based on 10 years of experience) being ranked 6^{th} for blade ratio and tertiary blank production and 4^{th} for regularity and completeness of assemblages. There were also instances where intermediate and expert knappers would, in different assemblages, produce blades and debitage that could be defined as both expert and novice. Core morphology was found to effectively highlight levels of skill with novices abandoning cores with step fractures and shattered platforms, in line with the patterns highlighted by Shelly (1990: 188-191). Expert knappers were able to cope with raw material vagaries and rejuvenate cores by removing crested blades thereby not abandoning cores until they were effectively exhausted. The mixed patterns of debitage and attribute analysis showed, despite differential quality in final blade production, that many characteristics were present in the assemblages of so-called novice, intermediate and skilled knappers alike.

Ranking	Blades	Tertiary blanks	Regularity	Completeness
1	B	B	C	A
2	A	E	B	C
3	C	A	A	B
4	F	C	D	D
5	E	F	F	E
6	D	D	E	F

Table 2.1. Relative ranking of knappers A – F, based on percentage frequency for their performance in all their Individual Events. There is obvious discrepancy as the letters were originally allocated to each knapper on the basis of their level of skill, with Knapper A technically the most skilled and knapper F the least skilled.
(Finlay, 2008: Table 5).

The presence of such overlap, produced in an experimental setting, raises questions of our ability to identify skill and the acquisition of skill in the archaeological record. If looked at without the prior knowledge that some members of the experimental cohort were classified as expert knappers (based on self-certification and hours of experience), it would have been easy to interpret the experimental assemblage as a product of several different sets of circumstances e.g. a mixed ability cohort; a group of novices being instructed by experts, or a group of intermediate knappers. Considering these possible variations, and using only the techno-stylistic attributes apparent from the archaeological record, Finlay (2008: 86-87) interprets an excavated assemblage from a Mesolithic site in the Scottish Southern Hebridean islands as the work of mixed-ability knappers. However, she does not rule out the likelihood that the degree of variation in apparent skill could have been caused by the inconsistencies often produced by moderately skilled knappers, revisiting the site on different occasions. Excepting variation in levels of skill, such inconsistency could also explain differences in style of flake removal and production of organised debitage in Oldowan contexts such as Lokalalei 1 and Lokalalei 2c (discussed earlier). It is because of this uncertainty in interpretation that Finlay (2008: 88) regards consistency of technical ability as such a valuable measure of skill. On this basis, she calls for the undertaking of more long-term studies enabling the recognition of the techno-stylistic transition from novice to skilled knapper.

Williams & Andrefsky (2011: 865) state the importance of the vertical and horizontal skill acquisition processes in creating variable styles of knapping, which could indicate the common or divergent cultural affiliations that likely produced differing assemblages in the archaeological record (see also Figure 2.9). To explore this, Williams & Andrefsky (2011) recruited a cohort of five knappers, each with a remit to produce five early stage bifaces and to reduce five multidirectional cores. In this context, consistency is again an important issue when trying to detect the causes of variability between knapped assemblages. If variation is the product of differences between assemblages of the same knapper, then in the context of identifying inter-group or inter-individual cultural signatures, variability measures may be questionable. To this end, Williams & Andrefsky (2011) ran *ANOVA* tests on each variable, to test the consistency of their experimental knappers in the production of each individual debitage attribute for each assemblage. The eight attributes selected were: type of flake, cortex, weight, maximum linear dimension and width, maximum linear dimension of platform, and presence or absence of cortex and abrasion on the platform. If there was high inter-assemblage variability for any given debitage attribute, from any individual knapper, that attribute was excluded from later PCA tests exploring the likelihood that each knapper could be identified by producing a debitage with unique characteristics. In this context, and as discussed earlier with the experiments of Finlay (2008), consistency is a critical issue. For Finlay (2008), it was a measure for determining the different levels of skill and experience present in the archaeological record. For Williams & Andrefsky (2011) discounting inconsistency in the selected attributes, generally the result of lack of expertise, meant that debitage could be used as an indicator of conscious stylistic variation, likely the result of different techniques of cultural transmission.

Williams & Andrefsky (2011) concluded that different flint knappers do significantly impact on debitage variability, with differences most evident in the reduction of multidirectional cores. Looking at individual performances, knapper 4 consistently produced smaller flakes from the same sized platforms, when compared with the other knappers. Knapper 4 was also taught to knap by a different instructor to the rest of the cohort and although he/she had knapped for many years, probably had the lowest frequency of practice. However, the consistency with which smaller flakes were produced suggests knapping that was the result of a conscious and well reproduced effort, more the hall mark of stylistic difference than lack of expertise or practice. Separating differences in form caused by skill as opposed to stylistic difference is not clear-cut and factors affecting culturally produced variability are likely to be more complex than this study is able to reveal. Despite this, Williams & Andrefsky (2011) illustrated that beyond levels of individual experience, how knappers learn to make different tool forms and who they learn from, are key factors in accounting for techno-stylistic variability.

2.1.4 Cognition and experimental knapping

Although not directly analogous to the process of transition from unskilled to skilled knapping, Stout *et al's* (2008) evolutionary approach to the *connaissance/savoir-faire* continuum defined by Pelegrin (1990; 2005), examined the differences in perceptual-motor skill and cognitive ability required to reproduce Oldowan and Acheulean technology. The first archaeological appearance of Oldowan technology at Gona, Ethiopia, is dated to 2.6 mya (Semaw, 2000). Described as a least effort technique to remove a flake with a sharp cutting edge (Schick & Toth, 2006: 4), Oldowan appears a conceptually simple technology. Stout & Chaminade (2007: 1092) upgrade this view and state the process of detaching a usable flake requires visuomotor skill involving the coordinated action of both hands, to facilitate a process based on an understanding of fracture mechanics, core morphology and appropriate use of platform angles. By comparison, Acheulean technology or biface manufacture also requires a process of *façonage* or specific tool shaping (Inizan *et al,* 1999). This is a process that involves understanding symmetry and requires a more structured and hierarchical approach to producing a tool possessing a high degree of predetermined form; a stark contrast to the simpler process of flake removal and expedient core reduction usually associated with Oldowan technology. This level of technological and putative cognitive advancement, in an evolutionary sense, is paralleled with the expansion of hominin brain capacity (Figure 2.3). Such techno-stylistic advance should however, not be confused with more curated and systematically knapped Oldowan assemblages such as those from Lokalelei 2c discussed in section 2.1.2. These assemblages are likely the product of more skilled and practised hominin knapping ability, not a speciation event or increased brain capacity. Accompanying the increase in cranial volume seen with the grade-shift from *Homo habilis* to *Homo ergaster* and the respective move from Oldowan to Acheulean technology, is the strong likelihood that brain function and organisation also changed (Holloway *et al* 2004). Stout *et al* (2008) builds on a previous body of work (Stout *et al,* 2000; Stout, 2005; Stout & Chaminade, 2007) by using PET and MRI technology to examine the neural substrates and areas of brain activation associated with producing Oldowan (Mode 1) and Acheulean (Mode 2) technology respectively. The aim of this research was to discover if there is a cognitive and sensorimotor progression required in the shift from Mode 1 to Mode 2 technology and whether there is a time-lag between evolutionary ownership of the cognitive prerequisites i.e. possessing the *connaissance,* and acquiring the *savoir-faire* to produce specific forms of lithic technology.

In Stout *et al* (2008) the three subjects involved in the PET experimental programme were instructed to undertake the following tasks. Firstly, to act as a control, using both left and right hands, they struck stones together to achieve a visuomotor base line not involving the engagement of any substrates involved in achieving the percussive accuracy and angle recognition involved in the tool making process. The second task (simple Oldowan), was to produce sharp edged flakes, without focus on core reduction that would result in a specific core form at the end of the process. The third task was related to bifacial technology and required the production of a late Acheulean handaxe, a process expected to involve engagement of more complex sensorimotor and cognitive skillsets.

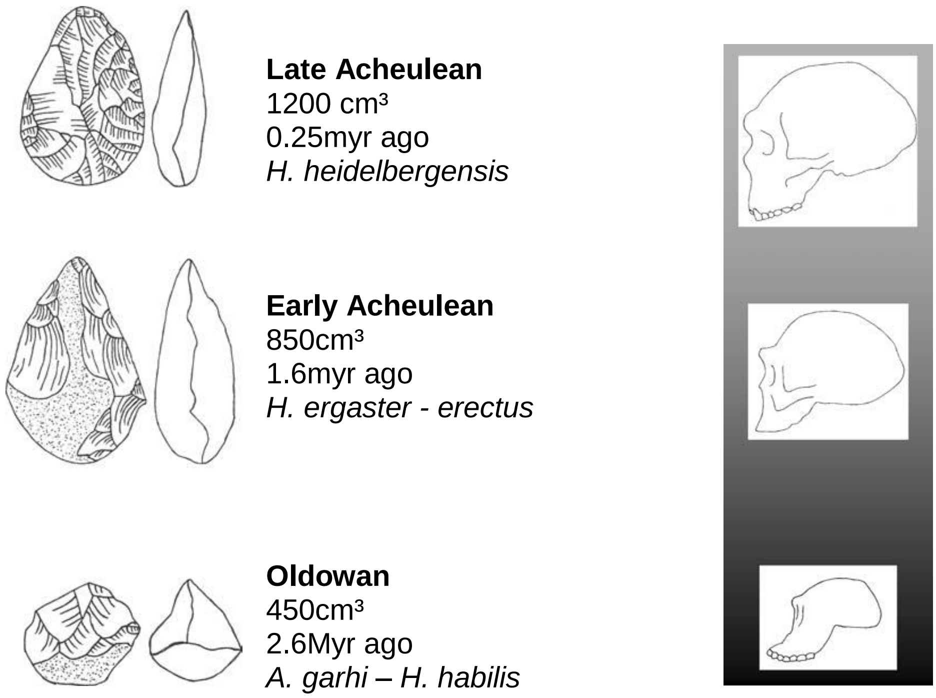


Figure 2.3. Early Stone Age (2.6 Myr – 0.25 Myr ago) technological and biological change.
(Modified from Stout *et al,* 2008: Figure 1).

With the caveat that functional imaging of brain activity in modern humans does not directly replicate the cognition and neurology of earlier species of hominin, Stout (2008) revealed the following; flake removal, over simply banging rocks together, resulted in increased activity in the inferior posterior lobule (IPL) adjoining the inferior posterior sulcus (IPS). This illustrates the increased requirement that production of Oldowan technology places on higher levels of sensorimotor control and the substrates that relate to framing tool use as an extension of bodily function (Stout, 2008: 1944). When comparing Oldowan production with Acheulean, Stout (2008: 1946) shows there was increased activity in the prefrontal cortex (PFC), especially in the right hemisphere (RH), for the supramarginal gyrus (SMG) and the inferior prefrontal gyrus (IPG). The RH activity is associated with the increased importance of the left hand in supporting, rotating and positioning the preform as an integral part of the bimanual coordination required in the handaxe production process. PFC activation is associated with the structuring of complex action sequences, requiring working memory to hold and manage more complex sensorimotor tasks. Such tasks are more hierarchical and multi-stage in nature; a process fundamental to handaxe manufacture, where one action, such as edging, thinning or shaping defers to another in the process of producing the final symmetrical form.

The application of neuroscience and functional brain imaging, to the process of experimentally reproducing stone tools found in archaeological contexts, sheds light on the evolutionary process responsible for the cognitive requirements required to move from one mode of lithic technology, to the next. Such a transition also depended on hominin ability to source and identify appropriate raw material and to detach flake blanks large enough to act as the initial handaxe core (Isaac, 1969: 16); a process requiring control and mastery of an increasingly complicated *chaîne opératoire*. It is apparent from the above that there was likely a genetically generated grade shift in executive capacity and use of working memory that allowed movement from Mode 1 to Mode 2 technology. In the context of Olausson (1998), this likely forms the basis of any uniform ability that hominins possess to knap stone tools and is a process that laid the foundation for strategic thinking in modern humans. Stout and Chaminade (2007: 1098) raise the issue that once hominins had acquired the executive capacity to cognitively process at this level, mastering any mode of knapping depended on sensorimotor capabilities, which, as demonstrated by the contemporary knappers of Olausson (1998), can only be appropriately refined through continued practice.

2.1.5 Context and structure of skill acquisition

As the archaeological record of Mode 1 technology provides evidence of hominins displaying differential levels of knapping ability, Nonaka *et al* (2010: 165) raise the question of the type of learning that likely took place. The fact that early instances demonstrating advanced mastery of conchoidal fracture are rare, means, at this stage, transmission likely occurred in an informal or sporadic manner, described by Nonaka *et al* (2010: 165) as “promoted action”. Here, the novice is guided to certain action but fundamentally experiments via their own experience. This is similar to 'guided variation' (Boyd & Richerson, 1985: 9) but the fact that skill did not ratchet (Henrich & McElreath, 2003; Tomasello *et al,* 1993; Tomasello, 1994) and organised debitage in the Oldowan is very sporadic, indicates a limited degree of transmission. In this context, 'promoted action' is closer to the type of loose parental direction found in chimpanzee groups who practise nut-cracking, where trial and error forms the basis of the skill acquisition process (Visalberghi, 1993: 120). The fact that not all chimpanzee groups acquire nut-cracking skill reflects a transmission process possessing a weak spatial and inter-generational level of cohesion. Bril *et al* (2012) establish even simple flake removal as a more complex behavioural process when compared to nut-cracking. In this context, ability to control conchoidal fracture to the extent of predicting the exact shape of flake removal (Nonaka *et al,* 2010), implies the application of a more complex process of cultural transmission; a fact attested by the widespread nature of Mode 1 technology and its eventual advancement and application to the production of Mode 2 technology.

In his quest to establish human provenance of stone tools found in the archaeological record, Evans recognised the importance of demonstrating he could knap lithic artefacts possessing the same stylistic attributes by using techniques that were likely similar to those used in the Palaeolithic. To realise such skills, he employed a combination of methodologies utilising contemporary craftsmen involved in the manufacture of gunflints, at Brandon in the UK, together with various anthropological accounts of knapping from analogous cultures in India and North and South America (Evans, 1872: 18-22). This approach, although directed mainly at the pragmatics of knapping, laid the foundation of procedures used in modern ethnographic research into knapping and skill transmission. Stout (2002a) studied the adze makers of Langda, New Guinea and explored the physical aspects of knapping technology positioned as part of a socially situated context. This approach allowed first hand observation of the scaffolded style of teaching employed at Langda and the impact it had on skill transmission from novice to experienced knapper. In a similar vein, Apel (2008), although stressing a technological approach using *châine opératoire* to explore factors affecting stylistic variability, also followed Lemonnier (1990); Pelegrin (1990) and Dobres (1999) by realising the importance of the social context in the creation and transmission of technological information (Apel, 2008: 94).

To explore the issue of structure in learning and skill transmission in knapping, Apel (2008: 95-96) used an analogy drawn from linguistics, employing the following distinction; a technological element is a combination of gesture and intention mediated by using a tool, and a technological syntax is a combination of technological elements nested in a chronological sequence. He developed the analogy by stating that syntax, in a craft such as knapping, may be transmitted from parent to child (vertical transmission), whilst technological elements are likely to be transmitted by horizontal means. Whilst there is apparent confusion in this description, and transmission chain experiments need to be conducted on how different gestures and attribute combinations are passed on, it does recognise the hierarchical nature of the knapping process and the likelihood that different factors impact on different levels of the skill acquisition process.

To define skillset development, Geribas *et al* (2010), through a series of experiments comparing groups of novice and expert knappers, integrated the key technological elements of knapping into a ‘behavioural catalogue’ focusing on two main areas: percussion and rotation. Performance in percussion was evaluated against the following six criteria: percussion zone/point of percussion, hemisphere of percussion, face of percussion, percussion support, position of blank and angle of blow. Rotation criteria for each strike was classified either as unifacial (and degree of rotation within that i.e. 90°, 180°, 270°), or bifacial, according to which axis the rotation was turned along i.e. horizontal or vertical. Each group was instructed to knap a basic handaxe, using a model produced by an expert, as their target form. The knappers were video recorded and awarded arbitrarily ranked behavioural units according to how well they fulfilled the criteria in the behavioural catalogue, whilst engaged in the process of reproducing the target form. Geribas *et al* (2010) conducted correspondence analysis on the mean values of each behavioural element and discovered the main advances expert knappers made over novices was in the type of percussion support used, the position of the blank when knapping and the angle of percussion. Although these were the most fundamental differences, the overall conclusion was that effective management, or high mean scores for all criteria in the behavioural repertoire had to be achieved, before any plan of future action or structured knapping could be conceived and executed, or before a novice could progress to intermediate or expert level of skill acquisition.

2.1.6 *Châine opératoire*, social control and methods of instruction

From his many comments on selection of appropriate raw material and raw material provenancing (Evans, 1860: 288; 1872: 30) and his descriptions of reduction techniques from primary core to the point of final discard (Evans 1866, 385), it is clear Evans had grasped the importance of *Châine opératoire* as a vital tool in the process of experimental reconstruction. The American archaeologist William Holmes had, by 1894 (see Johnson 1978: Figure 1 & 2) already mapped out an evolutionary cycle covering the ecological and cultural consideration, technical process, and final output of the lithic production process. Refinement of such activity has tended to follow three distinct paths, those following a cultural-typological approach such as Bordes (1961a; 1961b), those following a functional approach as advocated by Binford & Binford (1966) and those championing a technical reduction process such as Dibble (1984) and Pelegrin *et al* (1988). A more contemporary approach explaining aspects of lithic variation is to consider skill as part of technology itself and as a more important factor in accounting for technological and typological difference than has previously been recognised. Bleed (2008) uses two assemblages of late Palaeolithic micro-blades from Araya and Kakuniyama in Japan, which are typologically similar but technically hide different treatments. By employing what he describes as an 'event tree model' to reconstruct the production process and to understand the causes behind the different technological treatments, Bleed (2008: 161) was able to identify the different skill levels present in the two assemblages, by differences in their respective success and failure rates at the blade detachment stage of the *châine opératoire* (Figure 2.4). The first six stages in the chain are the same for both sites, which at Araya leads to successful detachment of blades with a low production failure rate of 10%, compared to 17% at Kakuniyama. This higher rate necessitates the use of a core rejuvenation process via a second spall detachment, something that is not detected in the Araya assemblage. At Araya, raw materials were more distant, so it is possible that more care was taken and only expert knappers were involved in the production process or at least the final blade-removal stage. It is also possible the Araya knappers although seemingly more skilled on the basis of consistency, did not know about the possibilities of core rejuvenation. Within the complex mix of factors that likely impacted on cultural transmission of lithic technique, is the issue that higher skill levels may have existed but were not utilised on all occasions. In this respect, Bleed (2008: 165) saw the deciding factor in an evolutionary context; skill was honed when it contributed to success. In this way, improving skill and performance became part of the technology itself and thus, a factor that could be selected for.

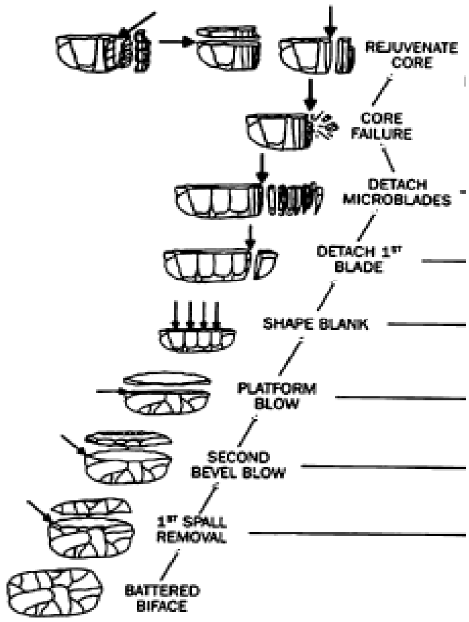


Figure 2.4. An event tree for microblade production showing the first 6 stages common to both sites but also early core failure occurring only at Kakuniyama and the extra rejuvenation stages needed to continue an efficient core exploitation strategy.
(Bleed, 2008: Figure 2).

Positioning skill, as part of an inclusive approach to examining factors affecting the cultural transmission of techno-stylistic attributes, requires the empirical approach to *chaîne opératoire* to be located in a relevant social situation. As already highlighted by Stout (2002a) and Pétrequin & Pétrequin (1993), the knapping practice and instruction sessions of the Adze makers at Langda were conducted in a heavily scaffolded group environment, supported by the social dynamic of the whole community. To put this in context, Stout's (2002a: 700 & 702) account of the Langda also illustrates elements of the control of raw materials, skilled personnel and those permitted to enter the apprenticeship system, generally governed on a hereditary basis by the head adze maker of Langda. In this respect the system of governance is self-perpetuating and controlled by the head adze maker who thus fulfils the 'aggrandizer' role hypothesised by Olausson (1998). This aspect of social control, regulating how a technology is culturally transmitted is also highlighted by Apel (2008). After learning the complex procedures involved in knapping the Scandinavian flint daggers of the late Neolithic (from Dr Errett Callahan), Apel (2008) was able to situate factors affecting the production process into an all-encompassing *chaîne opératoire* (Figure 2.5).

By grading the gestures and techno-syntaxes involved in learning each stage of the knapping process, according to the amount of *connaissance* they required relative to *savoir faire*, Apel (2008: 106) was able to identify seven stages and then points within stages where the transition from one level to the next was particularly problematic. This was primarily because it required access to specific levels of knowledge and practiced technique, likely relating to body position, strike angles and which specific tools to use. As the learning curve was so steep, Apel (2008) believes an institutionalised apprenticeship would have been necessary to transmit the knowledge and skill necessary to successfully knap late Neolithic/early Bronze Age daggers. Although the dagger knapping process is likely more complex than that of adze production, Stout's (2002a) ethnographic account (discussed above) bears witness to control of the learning process through such an apprenticeship. With regard to specific points in the *chaîne opératoire,* where levels of skill required need to make a significant advancement, enabling a threshold of *savoir-faire* to be crossed, Bleed (2008) uses a parallel example of blade production (see Figure 4). Here, skill is calibrated not only by the ability to remove blades after the core has been prepared, but to do it without failure, until the core is exhausted. Skill, in all these contexts requires expert levels of ability, understanding and consistency of action.

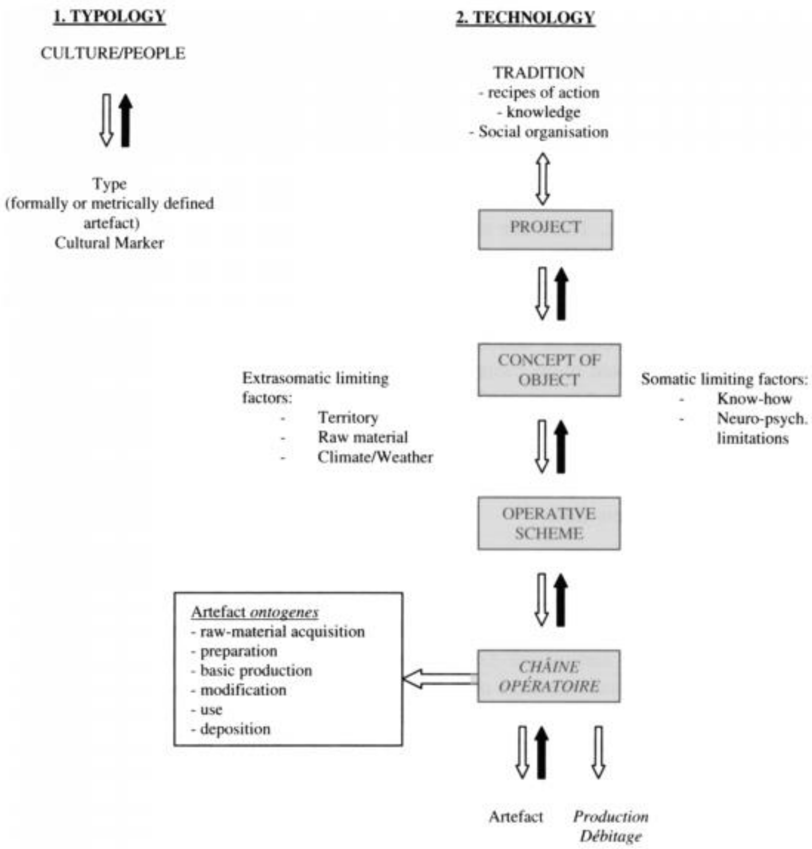


Figure 2.5. The *châine opératoire* (also compared with typological approach) highlighting controlling internal and external (ecological and societal) factors affecting artefact and debitage production.
(Apel, 2008: Figure 3).

Little work has been conducted on reconstructing likely methods of teaching and exploring the effects of different techniques on variation of stylistic attributes. Finlay (2008), in her study on consistency and variable skill levels, touched on the area by placing three members of the cohort into a collective, whilst two knapped in isolation. Those in the group were the least skilled knappers and counter intuitively, there was little communication between knappers during the reduction stages of the experiment, and the knapping preferences of each individual remained constant for the duration of the research. Finlay (2008: 75) reported the area where the most interaction occurred was in raw material selection and the pebble/core opening stages of the *châine opératoire*. The result of the group dynamic was the generation of a collective belief that they did not possess the strength to open the cobbles using a freehand technique. By contrast, both the individual knappers opened their cores using a freehold technique. Finlay (2008: 82) concluded that the knappers maintained their individual technological idiosyncrasies (e.g. platform scrubbing), but without prior knowledge of these behavioural traits, it would have been very difficult to refit or attribute certain assemblages to a specific knapper. In this instance, it seems consistency of variation between knappers was more a product of pre-existing skill levels than any differences produced by group structure, such as individual production versus collective production.

Evidence compiled from ethnographic studies (Pétrequin & Pétrequin, 1993; Stout, 2002a) and socio-economic reconstructions based on *châine opératoire* and refit analysis (Apel, 2008; Brooke Milne, 2005; Pigeot, 1990) support the idea that learning and skill transmission took place in group situations. To explore the likely methods used in lithic instruction, and their relative effectiveness, Ferguson (2008) created two groups, each comprised of four novice knappers. Both groups were taught to produce small projectile points by pressure flaking; however, group 1 was provided with verbal instruction only and group 2 were taught in a scaffolded scenario where demonstration and direct help was provided when required. Judged by a width/thickness ratio, the scaffolded group produced better points, of a usable nature, more rapidly than the group who received verbal instruction only. Due to the increased opportunity cost involved in raw material consumption and collection for the instruction of novices, Ferguson (2008: 59) believes the need to transform unskilled knappers into economically productive members of the group as quickly as possible, would require scaffolding or some form of organised apprenticeship. In this context, vertical transmission (expert instruction from members of the parental generation) would likely prove the most effective method of rapidly assimilating the necessary levels of skill. In larger group situations, especially where higher levels of skill are required, this is likely to occur in an oblique manner, where the instructors would not be directly related. Conversely, in smaller groups (as above), or where required skill levels were lower, cultural transmission is likely to be more vertical (from parents themselves). In both contexts, the goal of producing effective tools using raw material efficiently would seem to be the primary aim, but little experimental work has been done to test the most effective methods of lithic cultural transmission over multiple generations.

Ferguson (2008) also considered the archaeological misattribution of variation in lithic assemblages. As a more complete measure of the stylistic variability produced by each group, related to the differing skill levels produced by different types of transmission, Ferguson (2008: 64) created a coefficient of variation (CV) for each attribute measured (neck width, maximum length, basal width and maximum thickness) and then created an average CV for each group, together with the assemblages produced by himself as an experienced knapper. The resultant CVs were as follows: Ferguson, 12; scaffolded group, 17.6; taught group 21.1 (for full CV methodology see Chapter 3, section 3.5.2). Ferguson's (2008) conclusion was that levels of experimentally produced variation, although relatively small, if found in an archaeological assemblage would be enough to result in their attribution to a different typology or cultural group. In reality, the stylistic difference was generated purely by differentials in skill level and transmission technique.

The complexity and interrelatedness of factors affecting cultural transmission are such that the CV measures presented by Ferguson (2008) can be interpreted in several ways: firstly, they are measures of skill and ability to produce standardised form, in this case small projectile points. Secondly, they are measures of the effectiveness of two different types of transmission technique. In both cases, the CVs become lower with increased skill and better teaching methods. However, if the results are compared with CVs of other studies, such as Stout (2002a), the converse is true; as the knappers of Langda became more skilled, so their CVs started to increase (Ferguson 2008: 64). In this comparative situation, experimental and actualistic lithic research allows the exploration of different interpretative scenarios. Ferguson's (2008) cultural/teaching boundaries were tightly defined. His novices, in the limited time they had, replicated the technique and form as they were instructed. In this instance control was direct and there was little room for guided variation to occur. The knappers of Langda were undoubtedly subject to indirect bias, but due to the length of their apprenticeship (Stout 2002a: 702) were also likely to have produced adzes where guided variation and personal experimentation enabled them to demonstrate their skill levels and individuality. In this context CVs would increase with skill but are likely indicating a completely different aspect, or aspects of the cultural transmission process. Rather than stifling displays of individual stylisation, it is likely that within the constraints imposed by functionality, individual displays of expertise may have been actively encouraged, to further bolster the social and symbolic importance attached to knapping and the adze production process. In this respect, increasing CVs likely indicate that the achievement of high levels of skill was being used not only to reinforce the position of the cultural transmission process itself but also its situation within the wider society.

2.1.7 Methodological lessons

The majority of studies utilised in this section focus on the key themes of cultural transmission in lithic experimentation (discussed under each of the section subheadings). The issue that all of them struggle with is that of expertise. Knapping is a craft that is unfamiliar to scholars in the contemporary world; a factor that Evans also struggled with and would have been less able to overcome without the *savoir-faire* of the craftsmen who knapped gunflints at Brandon, in Suffolk. Opportunities for ethnographic study are now also few, with Stout (2002a), Roux *et al* (1995) and Pétrequin & Pétrequin (1993) being rare exceptions. The time taken to reach competent levels of ability, even at basic levels of Mode 1 or Mode 2 technology, often precludes studies that are able to focus on a longer term development of knapping skill. Ferguson (2008) effectively addresses the issue of differing skill acquisition techniques with two groups of knappers, each subject to varying styles of teaching. His choice of projectile points as the target form was admirable as an aesthetically pleasing and complex example of lithic material culture. However, due to the limited numbers of knappers available and the training time required to reach that skill level, Ferguson (2008) ran into the inevitable problem that variation in form could only be examined over a single generation of copies. The issue of representing only a single copying iteration is compounded by that of small sample size. In the first instance, Ferguson (2008) could have picked a simpler technology to reproduce, enabling more knappers to participate in the study, thus yielding a larger sample size. The fact Ferguson (2008) did not take this approach allows scope for future research to utilise the ideas he presented on the effectiveness of scaffolded versus unscaffolded teaching scenarios, by using simpler technology passed down through multiple generations of knappers, instead of just a single generation or copying iteration. Such a scenario would be more reflective of multi-generational knowledge transfer and stylistically generated variation in form, thus utilising limited sample sizes and available skill levels more effectively.

Another key issue presenting difficulty in research on lithic studies is that of raw material, which, in an experimental context, should be as homogenous as possible to discount variation in reduction strategy and knapped form caused by inconsistencies such as irregularity of shape, inclusions or differing conchoidal properties (Foulds, 2010). The studies focused on in this thesis have dealt with this issue in a variety of differing ways, generally dictated by time and budgetary constraint. In their early research, Dibble & Pelcin (1995) used plate glass, which was refined after access to increased budget, by using moulded glass cores in Dibble & Rezek (2009). For experimental handaxe production, Geribas *et al* (2010) used Spanish house bricks to provide a standardised blank with conchoidal flaking properties. The disadvantage with this is the very angular nature of the corners and edges making access into the core difficult for novices (pers com. Bruce Bradley). Williams & Andrefsky (2011: 866) used actual flint nodules that were "deemed to be largely free of visible inclusions that are prone to cause unexpected fracturing". Although this approach may introduce unnecessary doubt into the methodology, if the raw material selection process is part of the procedure to be undertaken by the experimental knapping cohort then it can be considered valid; the knappers in Williams & Andrefsky (2011) were instructed to select their flint cores from a wider sample provided to them, thus building an element of raw material selection into the experimental structure. In his study on differing teaching methods, Ferguson (2008) provided his cohorts with pre-struck obsidian flake blanks from which to knap projectile points. Obsidian is a valued and naturally occurring raw material that is highly homogenous in nature, lacks inclusion and is relatively easy to flake for knappers of all skill levels but, it is problematic to obtain in large quantities (Whittaker 1994: 69). The above examples illustrate the difficulty of overcoming problems of heterogeneity and provenancing and it could be said that none of them really present a viable or easily achievable answer to circumventing these issues.

Following comment made by Whittaker (1994: 68) about the suitability of porcelain for knapping and how it behaves more like naturally occurring raw material than glass, there is an opportunity to fashion a relatively low cost solution to creating large amounts of homogenous raw material. The use of high grade porcelain clay, shaped by using predefined moulds that can be formed either to replicate archaeological examples or idealised core forms, once kiln-fired, provides a raw material with consistent conchoidal characteristics and standardised form. In the context of transmission chains or experimental designs where large volumes of material are required over extended periods of time, the use of moulded porcelain appears to offer a solution more viable than many of those discussed.

Even with homogenous raw material, experimental exploration of cultural transmission using transmission chain techniques is always subject to difference in ability. A cohort of knappers will always represent differing degrees of ability; a phenomenon that is seen to occur even at the most basic level of flake removal (Bril *et al,* 2010; Nonaka *et al,* 2010). This presents unavoidable constraints when trying to isolate either stylistic drift or, genuinely idiosyncratic and consciously driven techno-stylistic change. Such differences have to be separated from the background level of variation that will be present in any lithic assemblage, due to limitations of skill. The difficulties lie in deciding what a normal level of variation is and how to recognise and explain variation that goes beyond normal levels. The issues of controlling for raw material variation and identifying the differing levels of skill required by different modes of lithic technology, in an experimental context relevant to exploring cultural transmission of lithic variation are addressed more fully in Chapter 3.

The objectives of experimental (and ethnographic) archaeological research into lithic technology have their roots in the primary concerns of Evans, which initially related to proving the human authorship and pre-biblical chronology of stone tools. If there is one primary theme that a developed and enhanced research paradigm has grown to work under, it is that of control. At the most intrinsic level, control relates to management of the bio-mechanic forces that form the basis of the knapping process. Specifically, at the level of the individual hominin, that control may not always have been part of a cognisant process, but it was learned and mastered through an array of different cultural transmission techniques. Through their experimental work amongst chimpanzee communities, initially conducted on chimpanzees in captivity that were subsequently released into large outside enclosures, mimicking their natural habitat, Hirata & Hayashi (2011) reported on observational learning of tool use involving hammerstones and anvils, to crack nuts. They commented on how the process was not learned by randomly directed trial and error but by the infant chimpanzees developing a systematic understanding of how the tools worked in specific combination, in conjunction with controlled force, to release the nut from its shell. Matsuzawa (2011) explained that such cultural behaviour is often unique to specific chimpanzee groups who develop their own traditions, which, in the first stages of transmission are directed by the mother. However, later in the chimpanzee's life, the necessary aspects of bio-mechanical control required for such procedures were observationally learned from other older members of their community, described by Matsuzawa (2011) as master-apprentice transmission.

Controlling and developing the level of skill required to maintain an effective lithic output is likely to have been an integral part of the social fabric of Palaeolithic societies, even at the level of the small hominin group. Control over skill development and techniques that were an integral part of the lithic *châine* *opératoire,* would, in some societies, have been a key part of maintaining cultural identity and/or power within that society. Such control could even be exerted at the most basic level of bio-mechanics governing the bodily movement of individual knappers and would certainly have affected the dynamics of cultural transmission. This section has highlighted studies covering all these areas, but critically, this reveals a lack of work focusing on transmission of lithic form and the skillsets necessary to produce that form over multiple generations of knappers. This is a key area of focus for this project and one where the use of transmission chain theory can enable the effect of differing cultural transmission scenarios on technique and stylistic form, to be more fully explored. This approach will form the basis of the experiments covered in Chapters 4, 6, 7 and 8. However, preceding that experimental programme, it is necessary to provide a theoretical outline of transmission chain experiments conducted as part of psychological research programmes.

2.2.1 Theoretical background of cultural transmission experiments

Two very different theoretical frameworks exist for experimental research on cultural transmission. In post-processual archaeology there has been a focus on human agency and socio-cultural relativism (Dobres & Hoffman, 1994; Dobres, 2000), while in memetics there has been a focus on analogies with Darwinian evolution in biology (Blackmore, 1999; Shennan, 2002; Richerson & Boyd, 2005). To reconcile these approaches, the notion of culture as something that is learned and socially transmitted must be incorporated into any evolutionary theory of cultural transmission. How close are the analogies between human innovation (usually seen as purposive) and genetic mutation (effectively random), between social learning (which may involve many combinations of transmitter and recipient) and genetic inheritance (which almost always involves vertical transmission by sexual or asexual reproduction) and between cultural selection (which is biased by criteria which we may not yet fully understand) and natural selection (a non-random process that can be explained in terms of reproductive fitness)? Apel & Darmark (2009: 13) discuss the issue of culture and cultural transmission as approached by scholars from different disciplines and point to failings on both sides of the resultant dichotomy: social scientists failing to see that relativism was generally underpinned by cultural universals and biologists regarding culture as primarily a genetically inherited adaptation. Apel & Darmark (2009) then talk of dual inheritance theory, which recognises the biologically evolved nature of human culture but also acknowledges that the transmission of culture through time and space represents a system of inheritance that does fulfil Darwinian principles of evolution. Following such a stance, this thesis explores the development of transmission chain theory and presents its findings under the following headings, which, are seen to represent key aspects of a more inclusive theory of cultural evolution.

2.2.2 Stylistic variation or cultural drift

Applying the Darwinian analogy to cultural evolution, the closest match for random mutation appears to be that of stylistic variation or cultural drift. This factor was identified by Evans (1875), sixteen years after Darwin (1859) published *On the Origin of Species,* and demonstrated that by applying archaeological seriation to early British coins, their ancestry via a system of 'descent with modification' could be traced back to coinage originating in Macedonia at circa 365 B.C. In attempting to isolate factors that impacted on random variation, Evans identified copying errors and artisan ability as key factors affecting how different attributes of each coin were reproduced from generation to generation. However, rather than adhering strictly to the analogy of random mutation (in the Darwinian sense), most of what Evans describes is descent with modification, but is far more directional than random in nature. At certain points within the resulting phylogeny of coin evolution described, naturalistic artwork would mutate to stylised representations, or changes in size and relative position of certain features would modify coin design. Despite these changes, linked strongly with the inter-generational levels of skill possessed by the artesans concerned, the parentage of the currency could still be identified and located in time and space throughout each generation in the seriation. In this sense, variation in skill level (generally its absence) led to a directional tendency for design simplification, stylisation and symmetry, which allowed

Evans (1875) to lay the foundation for the application of Darwinian theory, albeit more directional than random in nature, to cultural evolution.

To separate socio-cultural influence on the evolution of form and to cement the idea of change as a random process facilitated by inheritance, research conducted in the 20th century has attempted to anchor the concept of stylistic variation or cultural drift, in a psychological paradigm. Ward (1949), in a series of lab-based transmission chain experiments conducted on a cohort of undergraduate students, used ink and paper blanks to reproduce a coin seriation, which as with Evans (1875) focused on examples from the archaeological record documenting design change between 4th century BC Macedonia and 1st century BC Yorkshire. Two linear transmission chains (Figure 2.6) were run in parallel, one having the template from the previous generation to copy, the other reproducing each coin design from memory, after a short exposure to the last reproduction. By measuring change as the material passed through the chains, differentials and speed of change could be identified. It took 14 generations for the former to cease resembling the coin seriation from the archaeological record and 7 generations for the latter.

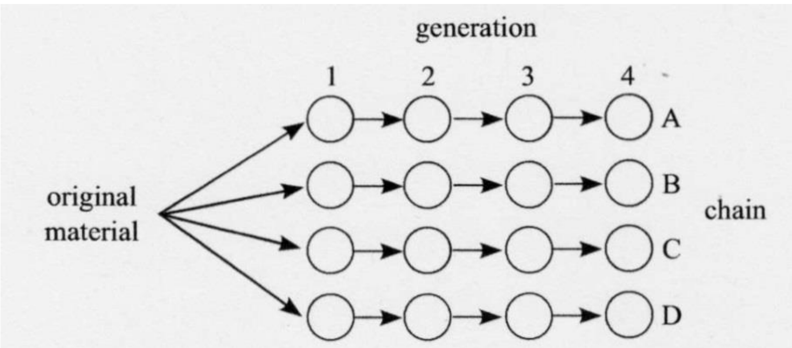


Figure 2.6. A general transmission chain design, here with four chains and four single member generations. As material passes through the chain, levels of design degradation can be quantified.
(Mesoudi & Whitten, 2008: Figure 1)

Ward (1949) concluded two further points: firstly, when comparing the method of reproduction and the longevity of the archaeological seriation, the original coin casters, in most cases likely copied the previous coin while it was present, as a template but were not directly taught or instructed. Secondly, change in coin design in both transmission chains and the original series can be attributed largely to human psychological factors. This deduction was arrived at because the experimentally produced designs were not subject to any socio-cultural pressure and in several cases shared similarities with the archaeological series, such as simplification of the laurel wreath and wheel, and centralisation or more symmetrical positioning of the wreath (p146). Ward (1949) believed such factors to be universal in nature and encapsulated in the human tendency to gravitate towards regularity, symmetry and simplicity when reproducing artefact form.

Exploring the cause of such tendencies has led to focus on human ability, or in many cases the unrealised error caused by limitations of memory, perceptual ability and motor skill. This was first explored in the 1830’s when German physiologist Ernst Weber established the notion of discrimination thresholds (Weber, 1834), meaning that small changes, below a certain threshold, could not be detected by humans without reference to external scales and measures; thereby establishing Weber’s Law. In the context of judging or perceiving differences in weight and line length, the relative (not absolute) thresholds were 2% and 3% respectively (Coren *et al,* 2004: 28). Eerkens (2000) explored this phenomenon further in a series of experiments where participants were asked to reproduce the shape of familiar items such as coins, credit cards, dollar bills etc., by using scissors and cutting their shape from paper. Eerkens (2000) builds on Weber’s Law by recording the standard deviations of all items reproduced and comparing coefficients of variation (CV). In addition to the 3% variation caused by human visuo-perceptual deficiencies, explained by Weber’s Law and identified by the threshold measurement for length, additional deviation from reproduction of a standardised form was judged to be caused by poor motorskills and deficient memory. This was measured by increases in variation, over 3% that occurred when greater periods of time elapsed between sight of object and reproduction. Although scissors are deemed accurate implements to work with, Eerkens (2000) believes his cohort were not expert in their usage, thus poor motor skills further increased the CV. This, together with work on pottery reproduction (Eerkens cites Longacre, 1999), where motor-skill issues are likely more relevant, also saw expert potters demonstrate high levels of variation, produced as a result of overcoming technical difficulty when replicating artefact form. Over and above the 3% length threshold caused by deficiency in visual perception, Eerkens (2000: 667) believes that poor motor skills linked to lower levels of hand-to-eye co-ordination can account for an additional range of variation of between 0.5% and 4%, depending on whether CV measurement is derived from an individual or groups of individuals. Where CV is consistently lower than 3%, Eerkens (2000) believes craft workers were likely specialists, using external methods of measurement and comparison.

Expanding the effect of psychological factors on cultural evolution, Griffiths *et al* (2008: 3503) introduce the term “inductive bias” to represent factors that affect memory and learning. Their work involves the transmission of information and the way people observe information (and its communicator), then reconstruct it according to certain personally held hypotheses before passing it on. Inductive biases that affect this process, resulting in one course of action being selected over another are: memory, communication ability and human perception of social convention. In a culture evolutionary context, Griffiths *el al* (2008: 3504) state, as a universal, all humans are subject to constraints in the way they learn, remember, make decisions and most importantly reconstruct information; generally imperfectly and according to their own inductive biases, before passing it on to a new generation. For example, two of their transmission chain case studies entailed the extension and continuation of geometric spatial sequences and required the grammatical structure of linguistic problems to be solved. In all cases where chain members had to develop an understanding of the problem before passing on learning related solutions, Griffiths *el al* (2008) discovered distinct patterns of convergence in the results after four or five generations of each chain, in each respective experiment. This pattern would hold true even if the first generation of each chain was presented with different starting data. The conclusions from these results are twofold; firstly, because of inductive biases, learning and reproduction of information from one generation to the next was not achieved at a high enough resolution to ensure accurate cultural transmission. Secondly, as concepts and language pass through a transmission chain, irrespective of the orientation of the chain, they will be adopted at a level matching the inductive biases of the members of the chain.

From this procedure, Griffiths *el al* (2008) posit the idea that inductive bias may be a stronger force in shaping cultural evolution than deliberate selection by an agent, on the basis of fitness.

It seems that variation and bias, either as a result of human psychological limitation or unconscious agency, has a very definite effect on the outcome of cultural transmission. Eerkens (2000) stated the 3% variation factor (plus the 0.5 - 4% dependent on group structure) does not account for technological or craft type and for techniques such as lithic reproduction, the factor is likely to be higher due to the reductive nature of knapping (Schillinger *et al,* 2014). Such an issue highlights the difficulty of illustrating the mechanics of Darwinian evolutionary theory applied to cultural transmission. Experimenting with archaeological attested techniques that are complex and practised by few modern exponents (and in the case of stone based technology, originally undertaken by a different species), presents real difficulty. Identifying random or stylistic drift as a separate generator of lithic variation, as opposed to change in form caused by differing levels of skill presents a task which will ultimately be resolved by analysing the magnitudes of variation present in specific transmission chains. Verifying the idea of convergence in form over multiple generations of copying, from different or random starting positions also presents further opportunity for transmission chain experiments focused on lithic technology. To aid in the exploration of such factors and to enable the construction of multi-generational chains handling production of physical artefacts, a new generation of experiments have emerged.

2.2.3 Skill acquisition and socially transmitted cultural evolution

To explore the variance in temporal and spatial rates of change illustrated by the archaeological record and to explain periods of stasis or rapid cultural acceleration, the idea that cultural evolution is a cumulative process affected by differing forms of social influence has to be considered. There may well be a base-line of random change affected purely by stylistic drift but to fully understand the cultural evolutionary process, the impact of socially transmitted factors (as a component of the inductive biases discussed above) must also be identified. Eerkens & Lipo (2005) also see such factors as “biases” on pure or stylistic transmission and create mathematical models exploring two types of bias: conformist-biased transmission (CBT) and prestige-biased transmission (PBT) or indirect bias. CBT is where each generation reproduces the most popular or commonly occurring variant found in the previous generation, and PBT is where the variant produced by prestige or status individuals is preferentially adopted over and above any other variant. The key issues here are: each bias will skew variation away from the distribution expected if solely random drift was at work and, the strength of both conformist and prestige biases will be variable, factors that are likely reflected in the archaeological record and can be built into the modelled data. The aim is to identify the type and level of bias present in the archaeological record by using the modelled data to help determine the type of transmission and methods of craft production or ‘teaching’ that formed the artefacts in question. Using the coefficient of variation for each iteration across multiple archaeological generations of projectile point thickness and basal width, Eerkens & Lipo (2005) concluded that production of Owens Valley projectile points (California) were subject to differing types of influence. Thickness of points varied at a rate of 5.8% per generation (Eerkens & Lipo, 2005: 326), in a way explainable purely by stylistic drift or copying error as discussed in section 2.2.2 above and modelled in Eerkens (2000). Basal width, far more sensitive to the technical performance of the arrow and an attribute that would govern the method of hafting used, varied very little over the generations studied. Eerkens & Lipo (2005: 327) concluded that initial experimentation led to an optimal basal width which was likely adopted under the influence of prestige bias and enforced on a temporal basis by a regime of conformist bias; an indication that this aspect of projectile knapping was likely taught in a scaffolded manner.

The forces governing levels of variation, not just in overall artefact form but in the specific attributes of the artefact, as demonstrated by the basal width of the Owens Valley projectile points, illustrates the interconnected but non-discrete nature of the culture evolutionary process. Although subject to the tight control of conformist or prestige bias in the temporal period focused on in the study of

Eerkens & Lipo (2005), there would have been a previous or initial stage in the evolution of Owens Valley point design. Before the optimal basal width for hafting was developed, there would have been a process of guided variation where an existing but technically unsatisfactory arrowhead blueprint would have undergone a process of trial and error development, not subject to the undue influence of any other design or individual producer. According to Boyd & Richerson (1985), this would have been 'guided variation' but only until the optimal basal width had been developed. At that point, direct bias becomes the dominant force as new arrowhead producers are only exposed to the optimal production technique, enforced by a culturally selective regime of scaffolding, governed by conformist or prestige bias. In this context, the types of bias cultural transmission is subject to are not static; they change over time and from one generation to next.

The impact of multiple generations on cultural transmission and the concept of cumulative cultural evolution have both been explored further with the use of laboratory based transmission chains. Caldwell & Millen (2008) constructed a series of ten generation chains with the following objectives: construct paper aeroplanes with the longest flying distance possible, and from a standard issue of spaghetti and clay, construct a tower as high as possible. By using the 'replacement method' of transmission theory (Figure 2.7a), the loss and replacement of each participant represents a cultural generation thereby forming a micro-society consisting of as many generations and members as deemed necessary by the objectives of the experiment. In this instance, each generation had a total of four members who joined and left the group on a staggered basis, with two members observing and two members producing at any given point, except for generations 1 and 10 (Figure 2.7b). In each case, Caldwell & Millen (2008) produced results supporting the idea that knowledge and know-how was transmitted through each chain on a cumulative basis, as the planes and towers of the latter generations, respectively flew further and were built higher than those of the preceding generations. Each task was performed by a series of different transmission chains and Caldwell & Millen (2008: 169) were able to draw Darwinian parallels by observing isolated instances of descent with modification, as designs within each chain had higher degrees of similarity than designs between chains. However, even considering this factor, convergent evolution was also demonstrated as the later designs of different chains became more similar than their earlier designs. In all generations of the series, evolution, in the sense of increased performance was shown to be a cumulative phenomenon.

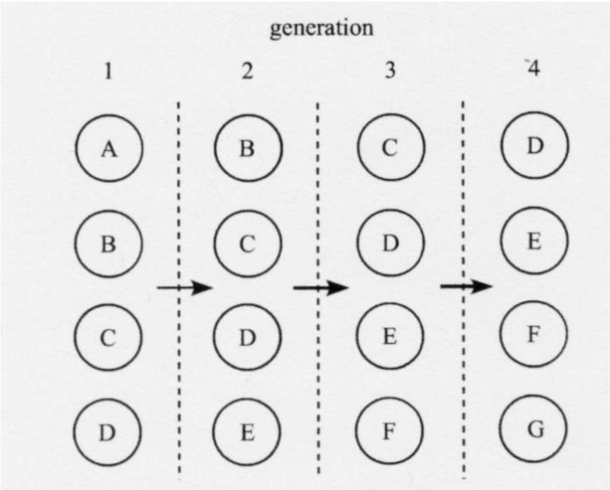


Figure 2.7a. A replacement orientated chain. Here, the progression of each generation sees an existing group member replaced by a new participant.
(Mesoudi & Whiten, 2008: Figure 2).

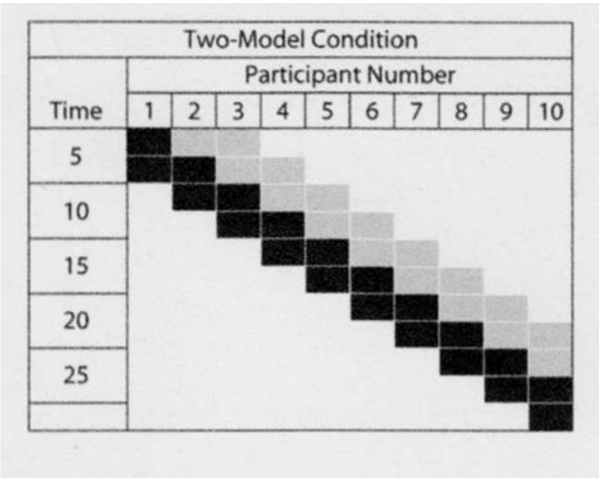


Figure2.7b. A staggered replacement chain, where, in each generation there are four members, two observing and two building. As one build is complete, that member leaves the group and is replaced by a new observing member. The existing observer starts to build and so the generations progress.
(Caldwell & Millen, 2010: Figure 1).

Verifying the idea of cumulative cultural evolution, which was the sole stated objective of their paper, Caldwell & Millen (2008) proved that as the designs passed through each transmission chain, results accumulated and performances improved on a generational basis. What they didn't address, as discussed above in the case of the Owens Valley projectile points, was the type of factors likely at work in creating that cumulative or ratcheted performance. In a replacement chain of ten micro-generations, with four people per chain, where experienced builders were replaced by observers or novice builders every generation, the social dynamics of each producing group would have been in continual flux. In this context, was cumulative cultural evolution generated purely by guided variation where design solutions were modified afresh, on a trial and error basis by each generation? Or, was direct bias the prevalent force, with each generation exposing the next to a limited number, or only one possible variant on which to improve? Affecting both these factors would have been the impact on each generation of the arrival or loss of new and old group members respectively and the likelihood that a more skilled tower builder or plane maker would influence the output of the group more than any of the other group members. In this context, was the accumulation of performance generated by prestige or conformist bias or, was each group combination equally egalitarian in the way they arrived at their final designs? To effectively answer those questions and to judge the likely functioning of cumulative cultural evolution, the impact of socially oriented inductive bias has to be factored into the equation.

Despite the neatness of the data and findings presented by Caldwell & Millen (2008), the reality of cultural transmission is undoubtedly a more complex procedure. Caldwell & Millen (2010) demonstrated this themselves when instead of cumulatively enhanced performance, neutral and negative performance results occurred when replicating their series of aeroplane experiments but with larger numbers of participants in each generation of the transmission chain. This begins to highlight the operation of other factors affecting skill acquisition in a social context, factors that Caldwell & Millen (2010) did not fully exploit in realising why performance started to decrease. Classic replacement theory (Mesoudi & Whiten, 2008: 3493) would seek to understand the respective impact of adding or losing of group members on the dynamic of each cultural generation. Introduction of gifted artisans could boost performance, however, a new group member with a forceful personality but less technical insight could result in a regression of performance. Equally, in an egalitarian group, increasing the cohort size could result in exceeding its optimal size for effective decision making, again, impacting negatively on levels of cultural innovation.

Transmission chain experiments also facilitate construction of control-groups to test the evolutionary validity of different cultural learning theories. Figure 2.8 shows the ‘closed-group’ method being used to compare the effectiveness of social learning against the multi-generational performance of individual learners. In a closed group, there is no change in the members present. This provides a solid framework for observing the impact of inter-group dynamics as member abilities begin to differ and participants decide who to copy or learn from, in the face of increasing technical complexity. In such scenarios, functions of prestige or conformist bias can be explored and in comparison with individual learners, rates of cultural change, stagnation, technical progress, design diversity and skill acquisition methods can be tested.

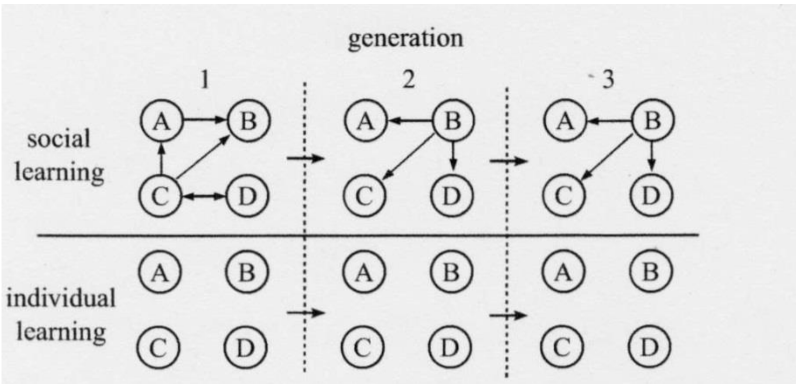


Figure 2.8. Two typical closed group designs where group members remain unchanged with social learning (top row) and no communication (bottom row). (Mesoudi & Whiten, 2008: Figure 3).

2.2.4 Complexity of skill-set

Although Caldwell & Millen (2008) are able to demonstrate the cumulative effect of guided variation (modification through trial and error), their focus is one of knowledge transfer involving a very simple skill-set. Tehrani & Riede (2008) believe the biologically evolved human ability to imitate provides the foundation for this behaviour. However, when considering more complex technologies, other factors in the skill acquisition process are necessary to allow for cumulative advancement and longevity in the transmission process. Tehrani & Riede (2008) state the level of skill transmission necessary to preserve such traditions must have involved direct teaching. This was not advanced verbal instruction (the current day conception of teaching), but guidance in learning routines of motor patterns, demonstration and gesturing with only limited use of language. Repetition of this direct or scaffolded approach would produce the cumulative mastery of skill and technique necessary to maintain or modify existing technology and methods of production. Eerkens & Lipo (2005) were able to decode two distinct forms of variation and transmission bias in their study of Rosegate projectile points from Owens Valley, in North America. By examining the CV of basal width and point thickness across a temporally stratified sample, they discovered the level of variation in point thickness was more in line with random stylistic drift, inferring there was little scaffolded teaching involved in the maintenance of specific point dimensions. Conversely, thickness of basal width varied very little, likely the result of a technical constraint, where inefficient shapes for hafting were winnowed out. Such low degrees of variation indicate the operation of conformist or prestige bias, where the most successful technical variant has been preferentially adopted. Maintenance of this level of standardisation, on a multi-generational basis, likely involved direct teaching employed either vertically or obliquely. In this context, analysis of *chaîne opèratoire* can identify not only technological procedure but also the likelihood and style of teaching.

The question of whether the human brain evolved to learn, execute and maintain complex technical procedures is approached by Mesoudi & O'Brien (2008a). By using a series of agent based models constructed to run across multiple computer-based generations, Mesoudi & O'Brien (2008a) compared the effectiveness, defined on a cost/benefit basis, of three different organisational structures likely involved in the skill acquisition process. The structures were: hierarchical, holistic and diffusionist. Each method of organisation/acquisition was modelled for vertical cultural transmission and individual learning. With the exception of very simple tasks, where procedure can be learned in a linear or piecemeal fashion, as is the case with holistic and diffusionist acquisition, Mesoudi & O'Brien (2008a: 70) concluded that skill is most effectively acquired in hierarchically structured sets of sub-routines. This falls in line with procedural sequences required in stone knapping. Here, each sub-routine is comprised of long chains of individual but interdependent procedural actions, and combinations of sub-routines are combined to form the final outcome. Mesoudi & O'Brien (2008a: 63 & 70) described these combinations as "cultural recipes" and in a biological analogy where phenotypes are transferred in a modular fashion, believe that in stone knapping, progression from one cognitive or skill level to the next is most effectively achieved by hierarchically combining modules of pre-learned sub-routines.

Mesoudi & Whiten (2008: 3491) consider that precise memory of cultural data degrades and recall becomes generalised because the cognitive processing of new information tends to assimilate itself with knowledge already possessed: a process supported by the constructive nature of using hierarchical combinations of sub-routines to form different cultural recipes (as discussed above). This view is also supported by Bartlett's work stating memory is not absolute; it loses detail and tends to reconstruct events or processes based on existing knowledge, perception and biases (Mesoudi 2008: 92). These factors, in combination with stylistic drift and biases derived from social learning, likely have a significant impact on the culture evolutionary dynamic. To understand the large scale temporal and spatial changes seen in the archaeological record, more work needs to be conducted on transmission chains, where micro-scale processes revealed in laboratory based experiments can be used to evaluate the wider process of cultural evolution.

2.2.5 Measurement of variation

To work effectively, variants of transmission chain theory (Figures 2.6, 2.7a & 2.8) need to reflect change demonstrated by the archaeological record. In determining aspects of drift or socially transmitted bias, what to measure at different points in the chain is a crucial issue. Experimentally, due to skill levels involved in archaeologically attested techniques such as stone knapping or pottery production, replication of culture evolutionary process is difficult. However, should that constraint be overcome, there are many studies where hypothesis testing with chains could replicate measures used in evaluating the original assemblages. In their study of changing projectile point form between North and South America, Morrow & Morrow (1999) proposed that the change from fluted point to fishtail point was not a product of social/cultural bias but was the result of stylistic drift. They arrived at this conclusion by creating a ratio of basal width to length, another for basal concavity depth to basal width and a lateral indentation index measuring four attributes, to provide an indication of how fishtailed the point had become. Geographic variation in these measures was compared on a temporal scale (derived from C^{14} dating), to reveal a gradual stylistic transformation in the outline point shape, likely the product of random drift and copying error. However, in-line with the ideas of Eekens & Lipo (2005), where changes in point form were a product of guided variation, a technically oriented direct bias was also limiting variation on the area of the point that would be hafted to the arrow shaft. This was demonstrated by the basal concavity to basal width ratio, which, remained essentially the same temporally and spatially between the Clovis points of North America and the more fishtailed points of both Central and South America (Morrow & Morrow, 1999: 222). Although an efficient study in the culture evolutionary process, any doubts about the conclusions of Morrow & Morrow (1999) would be minimised if the same process of measurement could be conducted on lithic data produced by series of experimental linear transmission chains.

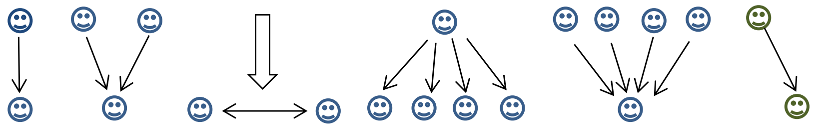
2.2.6 The missing link and future research direction

The key aspect missing from the research discussed in this chapter is experimentation with transmission chain theory using archaeologically attested techniques such as stone knapping or ceramic production. Gandon *et al* (2011) come closest to bridging this gap by illustrating the variation that can be generated when reproducing different ceramic forms, based on the difficulty of overcoming the mechanical constraints of clay, as measured by the Von Mises stress index. To avoid vessel collapse, even potters classified as ‘expert’ by

Gandon *et al* (2011) had to change key attributes when producing their copies of the target form. This compensation for the lack of ability needed to overcome the stress/form/skill equation was produced on a consistent and standardised basis (Gandon *et al,* 2011; Gandon *et al,* 2014). If plugged into a long transmission chain of real potters, the cumulative effect of such consistent changes would likely produce added insight in to understanding many archaeological seriations based purely on typological form. This is a practice that although highlighting temporal and spatial difference, has historically not focused on understanding the culture evolutionary factors that likely produced such variation (Mesoudi 2008: 97). The factors highlighted by Gandon *et al* (2011), focus primarily on directional form changes, consciously employed by the potters to overcome shortcomings in skill or technical ability. Gandon *et al* (2011) tended not to focus on the more random stylistic changes caused by visuo-perceptual and motor deficiencies, highlighted by Eerkens (2000). If these elements were also incorporated into the research design as part of the model or target form, and placed at the base of a transmission chain, they could form the basis of an integrated study on the cultural evolution of ceramic form.

To realise such an integrated study on cultural evolution, the research discussed in this section can be brought together and placed in a framework allowing the development of an effective methodology for testing each likely mode of transmission, its type of associated bias and generational structure with the relevant type of transmission chain (Figure 2.9). This would allow the formation of transmission chain protocols that are flexible tools for the generation or testing of archaeological and psychological theory. For example, as discussed in Section 2.2.3, Eerkens & Lipo (2005) could utilise the model illustrated in Figure 2.9 and use long chains of knappers to attempt replication of their stylistic drift theory. Building on that that, they could follow the Figure 2.9 model and select different group structures in multi-generational TCs, to reconstruct the biases they believed accounted for differing degrees of variation in basal width and point form, in the Rose Valley projectiles. To test the likely inputs of either directional form change linked to skill, or attribute variation linked to random stylistic factors, Gandon *et al* (2011) could (with more potters), use the Figure 2.9 model and select two single member TCs, one comprised of skilled potters, the other with less skilled potters. The more skilled group should be able to overcome the restrictions created by the Von Mises stress index and produce variation, throughout the TC, more in line with perceptual limitations. This is the approach adopted by Experiment 1 (the focus of Chapter 4), where copying in a TCP akin to horizontal transmission, in two groups of differing skill level will examine the level of intra and inter-group variation produced by multiple generations of copying a lithic blade form. Figure 2.9 is a compound model; adding to or modifying its original core (presented in black text) is a pivotal point of this research programme, as each experimental TCP explores different issues of the culture evolutionary process, related specifically to the production and transmission of lithic artefact form.

Modes of cultural transmission



	Vertical or parent to child	**Horizontal or contagious**	**One-to-many**	**Concerted or many-to-one**	**Oblique peer-to-peer**
Transmitter	Parent(s)	Unrelated	Teachers/leaders	Elders/peer group	Unrelated/peers
Transmittee	Offspring	Unrelated	Pupils/disciples	Youth	Unrelated/peers
Acceptance of innovation	Moderate	Easy	Easy	Extremely low	Easy
Variation between individuals	High	Can be high	Low	Very low	Can be high
Variation between groups	High	Can be high	Can be high	Very low	High
Cultural evolution	Slow	Can be rapid	Very rapid	Extremely slow	Can be rapid
Transmission Chain Type (s)	Single member or Closed group	Single member Closed or open group	Closed group with status member Open group with rotational novices	Closed group with group norm/ conformism Open group with rotational novice	Single member
To test type or cause of variation and type of bias					
Single transmission chain	Stylistic drift	Skill levels Conformist bias	Interchain/member drift and skill Guided variation	Directional change Conformist bias	Stylistic drift Guided variation or Direct bias
Multiple transmission chains	Skill and drift Indirect bias??	Group dynamics Conformist bias	Cultural bias Indirect bias	As above but also intra-chain	As above on an intra-chain basis Skill levels

Figure 2.9. Schematic representation illustrating modes of cultural transmission. Black text is from the original model of Lycett & Gowlett (2008). Blue text shows how each mode can be utilised by transmission chain theory to examine its likely effect on variation in form through multiple generations of copying. The final column (green text), is a variant of horizontal transmission.
(Modified from Lycett & Gowlett, 2008: Figure 3).

Ultimately, access to a limited number of skilled potters or knappers may constrain a multi-generational experiment representing large spatial and temporal spans. However, to overcome such limitations, to create a more inclusive protocol where the initial variables are derived from an archaeologically attested technique, macro-evolutionary time-spans could be generated by computer simulation. If enough knappers could be used to branch-off and form a separate and isolated chain, their variables, in conjunction with the parent group, could be simulated by the computer program to model cultural phylogenetic issues such as the occurrence of convergent/homoplastic evolution.

2.2.7 Conclusion

The fact that material culture repeatedly demonstrates descent with modification creates intense relevance for the processes that conveyed such change. Transmission chain theory is ideally placed as a vehicle to identify and isolate the relevant differences between stylistic drift and the cultural biases that affect the culture evolutionary process. Aspects of seriation, statistical treatment of archaeological data, human psychological capacity, skill acquisition theory and computer modelling of virtual agent based scenarios (Mesoudi & O'Brien, 2008b), when employed together, have the capacity to create a more comprehensive protocol for the development of an inclusive and Darwinian theory of cultural evolution. The most important area for this research to develop is that of bringing archaeologically attested craft techniques into the realm of transmission chain experiments; effectively a meeting of psychology and archaeology. With this in mind, the programme of experiments described in this dissertation has been designed to increase understanding of the material process and the evolutionary factors that shape it.

Chapter 3.

Materials and Methods

3.1 Introduction

The first half of the literature review in Chapter 2 covered the development of and advances made in experimental lithic archaeology, with specific focus on the knapping process and the attendant theoretical issues that have accompanied that area, since its published beginning in the1860 work of Sir John Evans. The second half outlined the issues underpinning psychological theory and experimental work designed to investigate the transmission chain protocols involved in exploring the differential evolution of cultural form through the mediums of human skill, transmission biases and human perceptual deficiency. Before the two respective sides of archaeological and psychological theory can be combined and applied to testing cultural transmission of lithic form, it is necessary that four key areas concerning materials and methodology are dealt with. Those areas are the focus of Chapter 3 and are as follows:

- Development of procedures for achieving the necessary level of homogeneity of raw material required for lithic experimental purposes, when utilising transmission chain theory.
- Training a cohort of subjects to reach the levels of skill required to knap two or three different types of lithic technology, with a level of skill sufficient to allow transmission chain methodology to function effectively.
- Development and application of techniques used to evaluate the differing levels of skill required by the transmission chain protocols, for each of the four experiments conducted as part of this study.
- Development of appropriate measurement techniques to capture the effects of differing TCPs on the lithic forms, as effectively as possible.

The objective focus of Experiment 1 was to achieve an idea of the level of variation present in lithic form, on an intra and inter-assemblage basis, as that form was passed through the generations of a single member, multi-generation linear transmission chain. Exploring the effect of differential skill level on the transmission of lithic form was also an objective, so, the skill possessed by each participating knapper had to be assessed in order to place them in the correct transmission chain (i.e. more skilled or lesser skilled). At this point in the project, the knappers had only a limited exposure to the conceptual knowledge and level of practise required to knap successfully (Chapter 2). Working with this constraint required the use of a technology which utilised simple levels of technical management, such as the repeated application of a limited range of motor skill to a specific but relatively simple knapping task. On that basis, it was decided that using a small preform core, designed for the production of short, 4 cm blades would provide the solution. The idea behind this rested on the understanding that the broader levels of skill necessary for blade making occur in the knapping and creation of an efficient core from which to remove the blades. This required the design of such a preform using homogenous raw material, to provide all knappers with a standardised core that was ready to strike blades from, meaning it had to possess the degree of preparation that matched the level of skill the knapping cohort could realistically attain, early in the duration of the project. Solving the issue of heterogeneous, naturally occurring raw material was discussed in section 2.1.7 and the procedure developed by the wider ‘Learning to be Human’ project, using porcelain to create the preform cores required by Experiment 1, is described in sections 3.2.1 – 3.2.4 below.

Experiments 2 – 4 were designed to explore issues of variation and transmission in the form of Acheulean handaxes. Here the same issue of providing each knapper, in all transmission chains, with a standardised preform handaxe blank from which to knap, is described in sections 3.2.5 – 3.2.7. The theory outlining the choice of such a form is explained in Chapter 5, which covers the background to the manufacture, transmission and variation of Acheulean handaxe form, explored by the experiments covered by Chapters 6, 7 and 8.

3.2 Core Construction Methodology

3.2.1 Experiment 1: Creating the mould

A blade core knapped from chert, by Bruce Bradley, was used as a model for the required target core form. The chert model was then replicated and shaped from clay (Figure 3.1) to overcome issues of uneven or projecting surfaces, natural on knapped chert. Such surfaces were found to obstruct the moulding process during testing of an earlier prototype model.

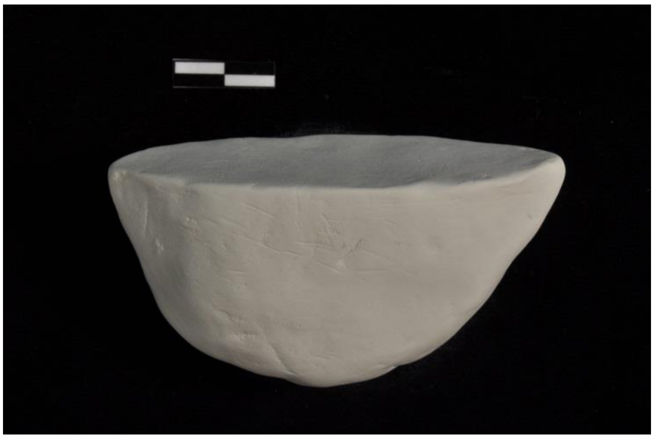


Figure 3.1. Clay replication of the knapped blade core used for the negative in the moulding process.
Photograph: S. Page

The mould was made by wrapping the clay model in cling film, and suspending it (using sticky-tape) from a wood spar so it hung in an empty 500ml container (a margarine tub provided a container of exactly the right size). The length of the cling film and tape was adjusted until the core was hanging at the correct height within the container, without touching the bottom or sides or projecting over the rim of the container (Figure 3.2). The wood spar was supported at both ends by a square frame. The core was removed whilst still attached to the length of wood. The 500ml container was filled with a liquid plaster made in a separate container, from ‘special moulding powder’ and water until it reached a creamy consistency. The suspended core was then lowered back in to position, to a point where the plaster just reached the lip of the core (Figure 3.3). It was left for 15 minutes until the plaster hardened and the core could be removed leaving its negative impression (Figure 3.4).

Figure 3.2.Creating the negative. Suspending the plaster mould at the correct height.
Photograph: A. Whitlock

Figure 3.3. Creating the negative mould with liquid plaster.
Photograph: A. Whitlock

Figure 3.4. The core negative after the plaster had set and the target form was removed.
Photograph: A. Whitlock

3.2.2 Core production: the porcelain selection process

The type of porcelain used for core production was chosen from a selection of premixed porcelain clays available from Ceramtech, a specialist ceramic material and equipment supplier based in north London. The two varieties tested were Royale porcelain and Special porcelain. Seventy cores of each type of porcelain were constructed and fired (see section 3.4.2 for firing procedure). Each batch was evaluated to decide which type of porcelain provided the most suitable and homogenous knapping material; the testing criteria is described below.

- In the first instance, they were trial knapped by BB. Three reductions from each batch of porcelain revealed, from a subjective view, that when blades were produced in accordance with the attributes specified in the TCP of Experiment 1, there was no discernible difference in level of flakeability or propensity for breakage during the knapping process.
- The quantitative results of the above knapping exercise are shown in Table 3.1. Royale porcelain shows a propensity to produce slightly heavier cores and marginally more consistent levels of blade weight and shatter when compared to cores made from Special porcelain.
- In the core production process, it was noted that although the Special porcelain was easier to mould, it had a tendency to produce more inconsistencies in core shape. This was likely the result of its more elastic nature and tendency to distort as a result of finger pressure in the final smoothing process, when compared to the stiffer quality of Royale porcelain.

The knapping differences highlighted above and presented in Table 3.1 were considered marginal by BB. With this in mind, it was felt by the author that Royale porcelain, although more difficult to mould, was a better raw material because it tended to produce a core shape with a more standardised topography after kiln firing. This, combined with the lower ranges of variation for the blade and shatter rates (Table 3.1), meant that Royale was the preferred choice of porcelain for the core moulding process.

	Weight (g)			
Test	**precore**	**core**	**blades**	**shatter**
XB1	115.2	39.1	70.0	4.6
XB2	116.9	37.0	71.4	8.2
XB3	115.6	45.7	65.0	4.7
B1	118.2	43.8	67.9	6.8
B2	119.0	43.2	71.5	4.8
B3	118.0	46.1	66.8	4.2

XB = Special porcelain.   B = Royale porcelain

Table 3.1. Knapping results of comparative porcelain testing. The Royale cores tend to be slightly heavier and produce marginally more consistent levels of blade weight and shatter.

3.2.3 Core production: the core moulding process

The Royale porcelain was supplied in cylindrical 12.5kg batches. Using a cheese-wire, slices 3cm thick were cut from the end of the batch. Each 3cm slice was then cut into quarters and roughly formed into a cuboid, approximately the same size as the mould. That shape was then fashioned, pushing, dragging and pinching the porcelain using the fingers of both hands until it was marginally less wide and thick, but taller than the negative of the mould (Figure 3.5). The top end of the porcelain was shaped to a point resembling the distal end of the core. The shaping process ensured this end of the porcelain would reach the bottom of the mould, allowing the distal end of the core to form properly. The negative of the mould was lined with cling-film, the edges of which should also overlap the sides of the container. This process allows the core to be removed from the mould later in the process. The plaster was then pushed into the negative, ensuring the mould was entirely filled before the excess plaster protruding from the mould was flattened down with the palm of a hand. A rubber band was then placed tightly around the diameter of the container to hold the cling-film in place. Pulling gently using fingers, the edges of this flattened plaster were slightly raised to form a lip; the cheese wire was placed under one of the narrower ends of this lip. Securing the narrow end of the container against one's body, the cheese wire was carefully drawn across the top of the mould, removing the excess porcelain. If any gaps were visible around the sides of the mould or there were small amounts of excess porcelain remaining, these could be pushed into the core-form using fingertips. The resultant core surface should be flat and flush with the top surface of the mould.

The core was removed from the mould by drawing together the protruding cling-film and gently pulling until it was released (Figure 3.6). After the cling-film was removed, any rough surfaces were smoothed by finger-tip, ensuring there was a sharp angle between the proximal end of the core and the lateral faces (Figure 3.7); this ensured all cores maintained a homogenous striking platform (for the removal of the initial blades), before they were placed in the kiln and fired.

Figure 3.5. Creating the initial core shape.
Photograph: A. Whitlock

Figure 3.6. Removing the set core
Photograph: A. Whitlock

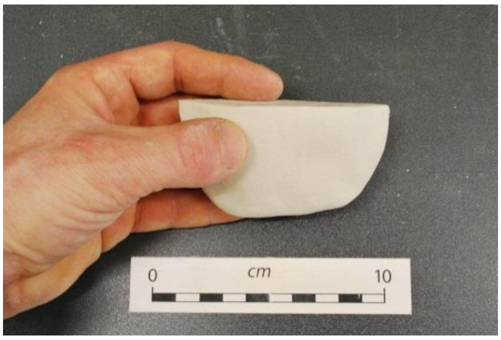


Figure 3.7. The final pre-fired core, after any irregularities had been smoothed off.
Photograph: A. Whitlock

3.2.4 Core production: the firing process

After moulding, the cores were air-dried for a minimum of three days in a room with an ambient temperature of 30° centigrade (measured using a thermocouple temperature sensor), at which point they felt warm and dry to the touch and were loaded into the kiln. The kiln used for firing all the cores used in this experiment was a P5976, made by Potterycrafts Ltd., Stoke on Trent, Staffordshire. To ensure that all cores were fully dried before firing, the kiln heating program was set to include a first stage of small temperature increases. Starting from 23° centigrade, the kiln's temperature was set to increase by 50° per hour until it reached 300° centigrade. The second stage of increases was set to climb by 150° per hour until the target firing temperature of 1,250° centigrade was reached. The kiln was set to 'soak' or remain at this temperature for three hours; once this had happened, the heating process was halted and the temperature in the kiln cooled naturally, returning to room temperature. To ensure standardisation of form, any cores that had cracked or become distorted during the firing process were discarded from the final batch selected for experimental knapping purposes.

3.2.5 Experiments 2 - 4: the mould making procedure

The shape required for the handaxe blanks and thus the mould making process for the handaxe preform cores was developed from the understanding that the earliest Acheulean began with the ability to detach large flake blanks from sizeable cobles or exposures where raw material was outcropping in veins (this subject is discussed in detail in Chapter 5). This process was replicated by using the pre-mixed porcelain clay and adapting the moulding, production and firing procedure developed for Experiment 1 and as part of the wider 'Learning to be Human Project', which also focused on the manufacture of standardised porcelain Levallois cores and arrow head blanks (Khreisheh *et al,* 2013). On that basis, six preform core rough-outs were shaped to resemble a large flake blank struck from a flint nodule, possessing a flat ventral face and a domed but smooth dorsal face. As with the mould for Experiment 1, the smooth surface of the dorsal surface allowed for the porcelain preform core to be removed from the mould more easily and ensured the regularity and consistency of the final core morphology.

Six handaxe rough-outs were created from 12.5kg packages of Royale porcelain, which were initially divided into even blocks (Figure 3.8) and then shaped and moulded by hand to resemble a selection of large tabular flake blanks. The most suitable (i.e. the largest and most uniform) was chosen to be the model from which to make a mould. Based on the success of the blade core prototype of Experiment 1, the flat ventral surface of the preform core replicated that of its natural counterpart by using an open mould that also facilitated fast manufacture of the reproductions by cheese-wiring off the excess clay from the exposed or top side of the mould. The preform core model was wrapped in cling film enabling it to be suspended. Plaster of Paris (sourced from an arts and crafts shop) was mixed with water according to manufacturer's instructions, and poured into a container, a cardboard box slightly larger than the preform core model, which was lined with cling film to make it non-porous. The handaxe model was then suspended in the box (Figure 3.9) and the plaster poured around it. When the plaster had set, the pre-core model was removed from the mould (Figure 3.10). Any small ridges in the surface of the mould, left by creases in the cling film, were carefully scraped away using a craft knife. The mould was then allowed to air-dry fully, for 2-3 days, ensuring it was solid and stable enough to use (Figure 3.11).

Figure 3.8. Creating porcelain blocks for the model preform core mould. Photograph: A. Whitlock.

Figure 3.9. Suspending the model to create the mould negative. Photograph: A. Whitlock

Figure 3.10. Removing the model. Photograph: A. Whitlock

Figure 3.11. The final preform mould Photograph: A. Whitlock

3.2.6 Experiments 2 - 4: preform core making procedure

The standard 12.5kg tube shapes that the Royale porcelain was supplied in had their rounded surfaces flattened, by using the palm of the hand, until a regular cuboid block (rectangular) was established. Using cheese-wire, that block was cut in two lengthways and then into thirds widthways, providing six smaller, flatter slabs of porcelain. Each slab was taller but slightly smaller in length and width than the negative of the mould. The slab was placed in the negative of the mould, which was lined with cling film, it was kneaded by hand (mainly using a reverse palm action) pushing and flattening the block until it completely filled the negative of the mould. The top was flattened by removing the plaster that stood proud of the top of the mould with a cheese wire, thus forming the smooth and level ventral surface of the preform-core. By drawing the cling-film together and lifting, the core was removed from the mould and the process was repeated until the number of preform cores required by each experiment had been produced.

3.2.7 Drying and Firing Procedure

After production, the cores air-dried for a minimum of 3 weeks (longer than the blade cores due to the larger volume of porcelain used in their construction), at room temperature of around 21 degrees. As some dried for longer than others a kiln drying programme was used to guarantee all cores were fired from the same starting point. The preform cores were stacked horizontally into the kiln, three in each layer, separated by three-point-stilts (two supporting and separating each core). The drying and firing programmes for the kiln were as follows:

Drying: from a starting room temperature of approximately 21 degrees Celsius, raising 5 degrees per hour until 100 degrees, then raising 5 degrees per hour to 150 degrees, then soaking at this temperature for ten hours; at this point the programme ends and the kiln cools naturally.

Firing: from a starting room temperature of approximately 21 degrees, raising 50 degrees per hour to 300 degrees, then 150 degrees per hour to 1250 degrees, at which point they soak for three hours, before the kiln is allowed to cool naturally. The firing procedure causes a small degree of shrinkage to occur, see Figures 3.12a and 3.12b and Figures 3.13a and 3.13b for pre and post fired cores respectively; the following dimensions offer a guide to the level of shrinkage that can be expected:

Unfired blank: length 21.2 cm; width 16.0 cm; depth 3.8 cm
Fired blank: length 19.3 cm; width 14.0 cm; depth 3.1 cm

Figure 3.12a Unfired preform core.
Photograph: A. Whitlock

Figure 3.12b Unfired preform core.
Photograph: A. Whitlock

Figure 3.13a Fired preform core.
Photograph: A. Whitlock

Figure 3.13b Fired preform core.
Photograph: A. Whitlock

3.3 Cohort training by lithic technology

The knapping cohort was drawn from members of the Archaeology Department at the University of Exeter and was a mixture of students recruited from undergraduate, masters and PhD degree programmes. Due to the wider research remit of the ‘Learning to be Human’ project, the successful training of a knapping cohort formed the foundation of three different research projects. The pivotal nature occupied by the cohort, in the wider project, ensured that training was undertaken in a structured and formalised manner. Led by BB, training for each type of lithic technology followed three main stages:

- Theoretical instruction using whiteboard graphics to illustrate the different geometric concepts underlying each technology and how to approach core construction and reduction.
- Actual knapping instruction on how to select different hammerstones, how to remove different types of flakes, construct platforms, shape, thin and manage a plain of intersection between the different faces of bifacial and prepared core technologies.
- Participation in organised and personal practice sessions, which each knapper was required to log.

Hours of instruction and practice undertaken by each knapper prior to Experiment 1 and Experiment 2 are displayed in Tables 3.2 and 3.3 respectively. As actual knapping ability at a given point in time is a better indicator of an individual's skill than stated hours of practise or years of prior experience, as was the case in Finlay (2008) and Olausson (1998), each knapper was required to perform an assessment exercise. Skill evaluation assessments were also undertaken as part of the requirements of the wider 'Learning to be Human' research programme and were undertaken by N. Khreisheh, at the University of Exeter. For the research on which this thesis is based, they were conducted before Experiment 1 and before Experiment 2 with the aim of indicating whether the participants had reached a standard of knapping compatible with the requirements of the blade or Acheulean handaxe experiments about to be conducted.

3.4 Skill assessments and transmission chain allocation

For Experiment 1, the assessment objective was also to allocate each knapper to the appropriate transmission chain based on their level of skill. For Experiments 2, 3 and 4, the objective was, more simply, to ascertain that the knapper had reached an acceptable level of skill to partake effectively in the experiment. This meant their handaxe knapping skills were sufficient to guarantee the transmission chains of each respective experiment would not prematurely break down, due to inadequate or unacceptably low levels of skill and that inter and intra-assemblage variation was the result of genuine skill differential, transmission bias or perceptual limitation. In accordance with the *connaissance* and *savoir-faire* components believed to define skill (Bamforth & Finlay, 2008; Pelegrin, 1990), in the context of harnessing understanding into a physical action producing a desired knapping outcome, the following procedure was undertaken.

3.4.1 Blade production: Experiment 1

Skill assessment specific to the lithic technology used in Experiment 1 focused on blade production. For each element of the evaluation i.e. *connaissance* and *savoir-faire,* each knapper was scored out of five, on an arbitrary scale, where one was poor and five was good. For *connaissance*, each knapper was presented with the same preform blade core and asked to verbally describe the reduction sequence they would undertake to detach five blades of approximately 4cm in length and 1cm wide, each with two parallel ridges. Their narrative was expected to cover elements of core preparation and the biomechanical knapping issues discussed in section 2.1.2, for example, where they would hit the core, at what angle, what kind of edge/core preparation they would carry out and finally, to predict what would be struck from the core, whether that be preparatory debitage or the final and desired outcome, such as a ridged blade. The narrative of each knapper was scored (assuming each removal occurred as stated), according to the accuracy of their predictions and how well their strategy was deemed to achieve the goals of the assessment. Following this process, they undertook the *savoir-faire* assessment, where scoring was based on the same criteria as for *connaissance,* but focussed on their ability to physically knap and achieve the debitage and specified five, double ridged blades they had previously described.

As the series of experiments undertaken for this thesis focused primarily on the ability to execute and produce a specified target form, skill levels were decided upon and TC groups formed primarily according to the *savoir-faire* score. The *connaissance* scores were applied mainly in marginal situations. This being the case, an average of the two scores was used to reach a final score for the subject's skill level. At this early stage in the development of each knapper's ability, there seemed to be a relationship between skill and hours of knapping i.e. the greater the number of hours of knapping, the better their *savoir-faire* score (see Table 3.2 for results of both tests). Knappers scoring three or above were allocated to the more skilled group: transmission chain one (TC1). Those scoring below three, formed the lesser skilled group: transmission chain two (TC2). To avoid the better (or worse) knappers clustering at any given position in each transmission chain, the knapper's position within the chain was randomly allocated, see 'Knapper Reference Number' for their respective placing within each TC (Table 3.2). Following this process, the first member of each TC was presented with the target form and the experimental protocol proceeded as described in section 4.3.1.

Knapper ref. no.	Hours knapping	*Connaissance* score	*Savoir-faire* score	Allocated TC	Position in TC
1	96.00	4.0	3.0	TC1	1
4	112.75	4.5	4.0	TC1	2
3	88.75	3.0	3.0	TC1	3
5	98.75	3.0	4.0	TC1	4
*16	7.00	3.0	3.0	TC1	5
6	109.50	5.0	4.0	TC1	6
8	32.25	3.0	2.0	TC2	1
2	72.25	2.0	2.0	TC2	2
13	21.50	3.0	2.0	TC2	3
18	42.00	2.0	2.0	TC2	4
9	11.00	1.0	2.0	TC2	5

Table 3.2. Experiment 1: Knapping hours, skill assessment ratings and transmission chain allocation by knapper. *Knapper 16 had previous knapping experience. Skill assessment and hours knapping data supplied by N. Khreisheh, University of Exeter.

3.4.2 Acheulean handaxe production: Experiments 2 – 4.

This series of experiments centred on the production of Acheulean handaxes or Mode 2 technology (Clark, 1968). Following the same procedure as for

Experiment 1, participants were given two scores, both out of five, based on their knapping knowledge (*connaissance*) and know-how (*savoir-faire*). The objective of the Acheulean handaxe skill assessments was to ensure that knappers reached a minimum *savoir-faire* score of three, before they could participate in the experiment. As there was no TC division on skill level, as in Experiment 1, it was essential that subjects taking part in Experiments 2 – 4 possessed a high enough level of skill to ensure the TCs did not break-down prematurely.

Connaissance testing procedure was as follows: each knapper was shown three handaxes, each at an increasingly advanced stage of completion; the same handaxes were used for each knapper and each evaluation, to ensure comparability. For each of the three handaxes in turn, each knapper was asked to describe how they would remove two flakes; those flakes should be the next two best flakes for progressing the technology. They were asked to describe the point they would hit at, the angle of their blow and to make a prediction of what they would remove. To illustrate this, they were instructed to draw each of their predicted removals on the surface of the preform handaxe core, with chalk. To accommodate the fluid nature of the knapping process and the degree of forward planning required, it was important that after each description, the account of their next removal took into consideration the fact that the core surface would have been changed by the previous removals. They were also told that their narratives may cover any platform preparation deemed necessary, to facilitate any of their specified removals. Each score was allocated on the likely accuracy of their prediction (Table 3.3), based on whether they were striking the core in a strategically sound place, whether their striking angles were suitable and whether their strategy for progressing the technology was appropriate and took account of changing core morphology as a result of their previously described actions.

For the handaxe *savoir-faire* assessments, each participant was given a porcelain preform core to produce a handaxe from; the knapping continued until they reached a point where they believed the piece to be finished or where any continuation of knapping would be detrimental to the overall form of the finished piece. As an integral part of the knapping skill assessment, subjects were required to select their own hammerstones, switching between and using as many different weights, sizes and materials as they deemed appropriate. No verbal or gestural instruction of any kind was given during the assessment procedures. The overall *savoir-faire* score awarded to each knapper was assigned more on the basis on their overall bifacing strategy, than on the final form of their knapped handaxe. Judgment was made by the project organisers, overseen by the senior PI (BB) on how the knappers created and managed the bifcial plane (the edge separating the two faces of the handaxe), the striking angles they hit the preform core at, the accuracy of their hits, their use of platform preparation, their choice of when to stop knapping, the confidence and competence of their blows, how they dealt with knapping mistakes such as step or hinge fractures and as previously mentioned, their choice and use of hammerstones. Results of *connaissance* and *savoir-faire* assessments, together with hours of pre-experiment practice, for handaxe production, are presented in Table 3.3.

Knapper ref. no.	Hours knapping	*Connaissance* score	*Savoir-faire* score	Position in TC1	Position in TC2
27	64.75	5.0	4.5	1	3
5	183.25	2.5	3.5	2	5
*16	11.50	5.0	5.0	3	1
6	188.75	4.5	4.5	4	7
18	79.75	3.5	4.5	5	2
1	199.75	2.0	4.0	6	6
7	221.50	4.5	4.5	7	4
2	87.00	2.5	2.5	-	-
4	206.25	3.5	3.5	-	8

Table 3.3. Experiment 2: Knapping hours, skill assessment ratings and TC position by knapper. *Knapper 16 had previous knapping experience. Skill assessment and hours knapping data supplied by N. Khreisheh, University of Exeter.

On the basis of the selection procedure outlined above, Knapper 2 was excluded from Experiment 2, on the grounds that the minimum *savoir-faire* score of 3 was not achieved (Table 3.3) and averaging the scores for *connaissance* and *savoir-faire* still failed to bring the knapper to the required level necessary, for maintenance of a credible TCP.

3.5 Measurement of lithic output

3.5.1 Experiment 1: basic blade metrics and discrete morphology

Measurement of the blades produced by the skill defined transmission chains was taken for key the attributes of length, width, thickness and weight. All pieces over 2cm in length were included; debitage smaller than this was excluded from the analysis. If a blade attempt failed because the piece broke as a result of inability to control the dynamics of the knapping process, it was also excluded from the analysis. Other attributes recorded varied for each knapper, dependent on the movement of discrete form throughout the iterations of each transmission chain i.e. as target form changed from one knapping generation to the next, so did the attributes of the target form that the subsequent knapper had to reproduce. Attributes in the analysis were recorded as follows, based on the knapped assemblages of all transmission chain members.

1. Continuous variables

Length, width, thickness, weight

2. Discrete traits

Central ridge – yes:no
Two lateral ridges – yes:no
Other ridge pattern – yes:no
Parallel edges – yes:no
Convergence to point from 2/3 of length – yes:no
Point form – yes:no

3.5.2 Analytical procedure for metric data: coefficient of variation

To enable the exploration of intra-assemblage variation and also allow for comparisons to be made on a cross-assemblage basis, in her work on ceramic standardisation, Roux (2003) utilised the coefficient of variation (CV).

CV is arrived at using the following procedure: CV = $\left(\frac{\sigma}{\boldsymbol{\mu}}\right) * 100$.

Following the lead of Eerkens & Bettinger (2001), Roux (2003: 772), stated that using the CV in this manner can be regarded as the best measure of assessing variation within assemblages. Roux’s (2003) primary research question focused on examining differing levels of variation found in the metric attributes of wheel-thrown ceramics produced on differing scales or levels of intensity, such as comparing high level production in communities with organised and dedicated resources, to low level production undertaken in communities with fewer and less formally organised potters. The division of each metric attribute’s standard deviation, by its mean, expressed as a percentage provides a size-independent variation not available from using standard deviation in isolation. This enabled Roux to compare, on a like for like basis, variation in assemblage attributes in the output of the different potters within each production level, when vessel types shared the same attributes such as height, aperture or diameter, but may have been of a different overall form. More recently, this approach was also used by Ferguson (2008) to detect the presence of children and novices in the archaeological record. Using the CV enabled Ferguson to compare levels of attribute variation in assemblages produced by a single generation of contemporary novice and expert knappers with the aim of comparing them with those of excavated archaeological assemblages. The results suggested support for Ferguson’s (2008: 64) hypothesis that CV decreases with increased levels of skill. However, as this result was not supported by significance testing, it is difficult to confirm categorically; also his methodology was not able to control for other factors likely to influence the CV, specifically the key issue of variation in raw material quality, which, if not controlled for, could skew or mask results considered to be purely an outcome of differing levels of skill.

3.5.3 Analytical procedure for combining metric and non-metric approaches

As blade shape is an important criterion in assessing variation and change in form, additional width measurements were taken at key points along the length of each blade; 10% from butt, 50% from butt (midpoint) and 90% from butt. For each removal, three indexes were created to gain relative measures of taper. The first was an overall measure of taper (90%/10%), the second, a measure of taper for the distal portion of the blade (10%/50%) and third, the proximal degree of taper (90%/50%). To provide comparable measures of shape and change of form, analysis of means and standard deviation for each taper index was then undertaken and grouped according to the non-metric attributes produced by each TC and each knapper. Those non-metrics were for ridge patterns: ‘central’, ‘lateral’ and ‘other’ and the typologically assigned shapes: ‘parallel sided’, ‘convergent’ or ‘point form’. The objective of combining metric and non-metric approaches in this manner was to discover possible and significant linkages, defined by using Chi squared tests, between achievement of shape and achievement of particular ridge patterns. Chi-squared values were calculated using the following formula, where *0* = observed or actual value and *E* = expected value (Chi *p*-values were produced by using the Data Analysis package in Microsoft Excel 2010).

$$x^2 = \sum \frac{(O - E)^2}{E}$$

3.5.4 Procedure for measuring 3D Euclidean distance and level of taper

The emergence or evolution of form was further explored by examining the relationship between three dimensional shape and degree of blade taper. The three dimensions used were length, width and thickness and the difference between each iteration and the three dimensions of the base target form was presented as a measure of Euclidean distance. The formula for each removal’s

Euclidean distance from the target form, where *d* is difference, L is length, W is width and T is thickness, was calculated as follows:

$$\sqrt{(dL^2 + dW^2 + dT^2)}$$

The taper calculation used the butt (10%) and tip (90%) width measurements described in section 4.3.6, and was calculated as follows:

$$\frac{(10\%\mathrm{W} - 90\%\mathrm{W})}{(0.8 \times L)}$$

By dividing by length (x 0.8), the degree of taper (i.e. the difference in width between 10% from butt and 10% from tip), is presented as a proportion of blade length. This provides a more representative measure of overall shape by circumventing the problem with a simple taper index, that a shorter blade with a tip that is (say) 20% less wide at the butt will not be recognised as more acutely tapered than a longer blade with the same differential.

3.5.5 Standard handaxe measurement

All metrics were taken in accordance with the procedure established by Roe's (1968) system that defined standard measures of length, breadth and thickness taken at different points on the handaxe, plus the addition of a width measurement at 50% of length. All measures of continuous data, according to Roe's methodology, together with their appropriate notations, are as follows and are illustrated in Figure 3.14.

Maximum Dimensions

Wt: weight, L: length, B: breadth, Th: thickness.

Dimensions defining type or shape

B1: breadth or width at 20% of length from tip (or 80% from butt).

B2: breadth or width at 20% of length from butt.

L1: distance from butt to the widest point of the handaxe.

T1: thickness of tip at 20% of length from tip (or 80% from butt). T1 was only taken for pointed handaxes.

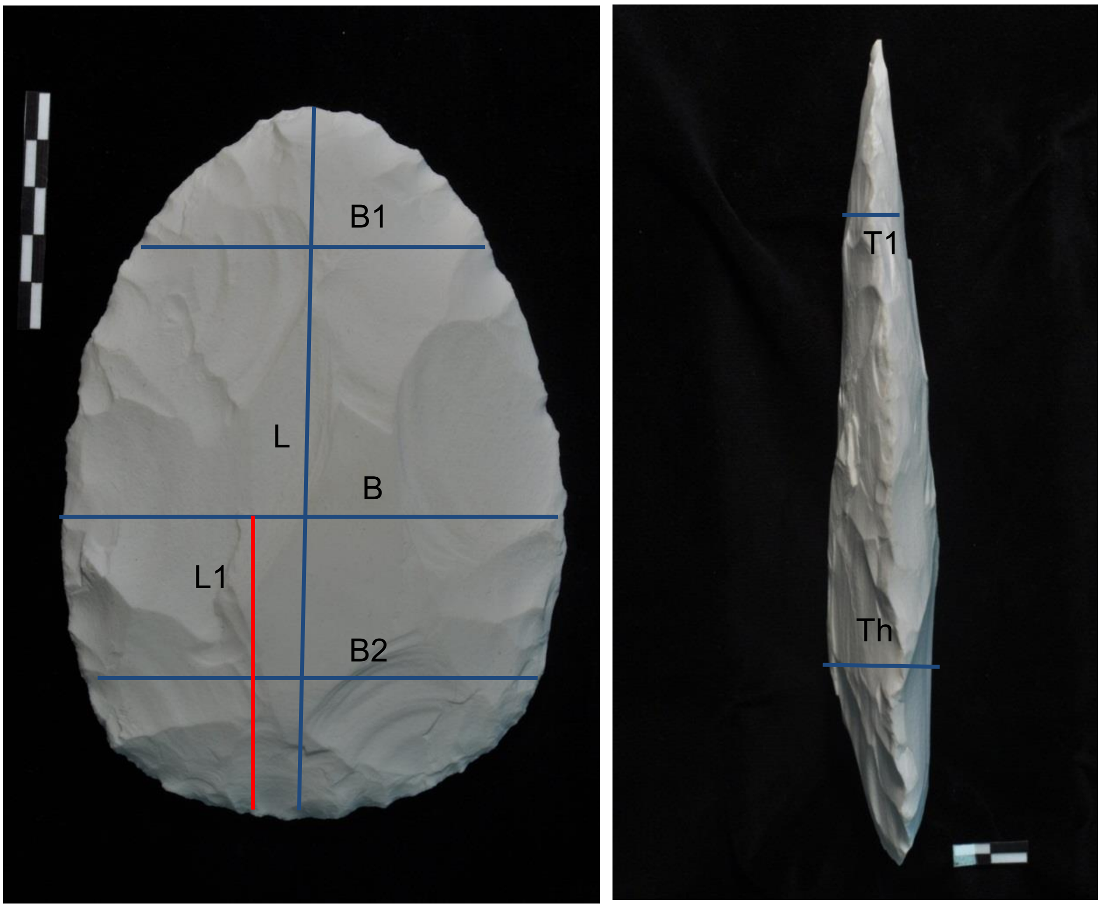


Figure 3.14. Plan photo of an ovate handaxe showing Roe's measurement points. Section/edge photo of pointed handaxe shows additional refinement measures. Photographs: S. Page

The above measurements were used by Roe (1968) to calibrate variation in size, refinement and shape, in the following ways:

Size preference was gauged by using the relative frequencies of weight (Wt) and length (L) measurements in each assemblage.

Refinement, defined on the basis that the flatter the handaxe, the more refined it is, was calculated using $\frac{Th}{B}$. For pointed handaxes the additional ratio of $\frac{T1}{L}$ was used, again taking flatness of tip as a proxy for refinement.

Shape, as a measure of relative broadness was calculated as $\frac{B}{L}$, where a lower value means a narrower handaxe. The degree of taper or ovateness was calculated using $\frac{B1}{B2}$ where lower values equate to more tapered handaxe. The most important measure of shape or relative pointedness/ovateness is based on where the handaxe's point of maximum breadth is located and was calculated using $\frac{L1}{L}$. In this instance, lower values mean the maximum breadth is nearer the butt end.

This measurement procedure, as highlighted by Debénath & Dibble (1994) faces the key issue of how the handaxe should be orientated before the dimensions were taken, in order to maximise objectivity and the ability to repeat the measurement process on a consistent basis. The first stage in this process was the identification of the long axis of symmetry. Following a macroscopic application of the process outlined by McPherron & Dibble (1999: 45), the length axis was identified by passing a sighted line through the handaxe from the tip to the butt (which were clearly identifiable in all cases), with positional adjustments being made until the difference between each side of that central line was judged to be as minimal as possible. To aid this orientation procedure, each handaxe was placed in a box-frame lined with graph paper (Figure 3.15). The 90 degree angle formed by the conjunction of the left hand and bottom sides of the box-frame was set to zero, with handaxe measurements taken to the nearest millimetre from that point upwards, vertically along the length or y-axis, and horizontally to the right, along the width or x-axis. Each handaxe was placed on its dorsal side (ventral side up) with its butt resting on the x-axis and left lateral side resting on the y-axis. When it was symmetrically oriented within the framework created by the sides of the box-frame and the graph paper, its position was anchored using blue tack and the tip was supported and kept level by different sized rubber blocks.

The porcelain composition of the preform cores from which each handaxe was knapped allowed the dorsal surface to be marked in pencil. After symmetrical orientation, the area of the handaxe's butt resting on the x-axis was marked in pencil and each handaxe remained in this position while the measurements were taken. Each point was then measured against the scaled graph paper and marked at the appropriate point on both lateral edges of the handaxe. The edge of the handaxe was vertically and horizontally aligned with the graph paper scale using a clear setsquare. Consistent repeatability of the process was enabled by re-aligning the handaxe within the frame according to the measurements taken and marked on the edges of the handaxe. As a check of standard orientation and accuracy, once all markings on the handaxe were correctly aligned with the previously measured distances, it could be guaranteed that each handaxe was consistently aligned. All length and width measurements were taken in this way with width measurements double checked using handheld callipers and the thickness measurement taken solely with callipers. Locking each handaxe into a frame and anchoring its position according to a set of landmark points measured and marked on its butt and lateral edges, created a consistency of process that produced standardised orientation and data, allowing metrical comparability on an inter and intra-assemblage basis.

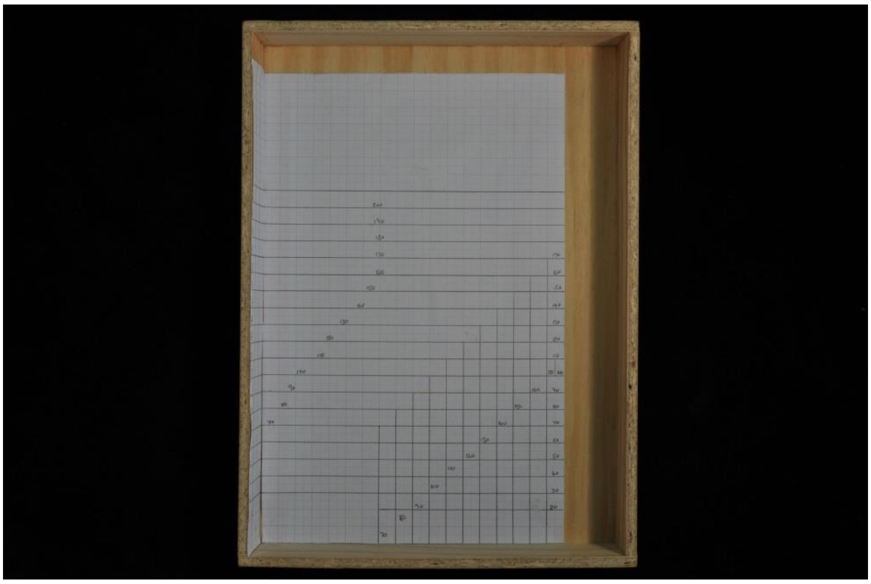


Figure 3.15. Use of a calibrated box-frame to orientate and measure each handaxe. Photograph: S.Page

3.5.6 Extended use of Roe (1968) metrics

As mentioned above and stated in the objectives of Experiments 2, 3 and 4 (Chapter 5, Table 5.1), in the first instance, Roe's system of measurement and resultant dimensional ratios was used to evaluate variation created by the differing protocols of each transmission chain. In addition to these, a more extensive system of evaluation was developed for use in this thesis (other methods of capturing variation in handaxe morphology are also discussed in Chapter 5). Experiment 1, although focused on blade forms, has already demonstrated the value of considering form as a product of more than two metrics (the approach used in Roe's ratio based system). By using analysis based on standard handaxe measurements, the following procedures, used in all the Acheulean experiments that are part of this thesis, were designed to create additional measures of taper and of three-dimensional shape.

- Taper - the taper calculation uses the butt (20%) and tip (80%) breadth measurements, resulting in the following formula:

$$\frac{(\mathrm{B2} - \mathrm{B1})}{(0.6 \times L)}$$

By dividing by length (x 0.6), the degree of taper (i.e. the difference in width between 20% from butt and 80% from butt) was presented as a proportion of handaxe length. This provided a more representative measure of overall shape by (as in Experiment 1) circumventing the problem with a simple ratio (as used by Roe), that a shorter handaxe with a B1 measure that was (say) 20% less wide than B2, will not be recognised as more acutely tapered than a longer handaxe with the same differential.

- Three dimensional shape – the aim here was to create a single combined measure of Euclidean distance from the base target form, in terms of length, width and thickness. The formula (as used in Experiment 1) was, in this case, used for each handaxe's Euclidean distance from the base target form, where *d* is difference, L is length, W is width and T is thickness, is as follows:

$$\sqrt{(dL^2 + dW^2 + dT^2)}\ .$$

The aim here was to progressively move away from the isolated use of firstly, two dimensional ratio measures and secondly, the sole use of linear measurements as gauges of refinement and shape. To progress that aim further, the following sections describe the use of measures derived from the digital processing of photographic images of the target forms, produced under the influence of each experiment's different and specific TCP.

3.5.7 Refinement: the use of ImageJ to produce area based measurements

Given the importance of the breadth to thickness relationship in gauging the effect of skill and cultural transmission on artefact form (Eren, 2013; Eren & Lycett, 2012), the single linear measurements forming the basis of Roe's $\frac{Th}{B}$ ratio (and $\frac{T1}{L}$ for pointed handaxes) appeared an insufficient measure for capturing the range of dimensional factors that could act as a proxy for handaxe refinement. On this basis, it was proposed that developing a system of analysis based on the entire surface area of specified attributes, meaning the plan and cross-sectional area in cm^2, would provide a more accurate representation of handaxe refinement. In addition to improving on the geometric based measures employed by Roe (1968), considering other attributes also seemed relevant to exploring iterational form change. Using cortex as a measure of reduction and curation is an established tradition in lithic studies (Andrefsky, 1994; Dibble, 1995; Dibble *et al,* 2005; Douglass *et al,* 2008; Toth, 1985). In the context of biface manufacture, production of a handaxe bearing little or no cortex, as was the case for the base target forms of Experiments 2 - 4, is a possible proxy for refinement and therefore a measure of drift, directional change or knapping skill as each copy passed through the generations, and was subject to the differing protocol of each transmission chain. On this basis, the two additional refinement measures used in this project involved the following:

- Exploring the relationship between total planform area (cm^2) and total edge area (cm^2), of each iteration of handaxe form, as a planned improvement on the use of purely linear measures.
- Exploring the relationship between the total area of remaining cortex on each iteration, related to the total surface area of each handaxe form.

The imaging possibilities offered by 3D laser and photographic scanning technology have begun to be explored in lithic analysis (Grosman *et al,* 2011; Lin *et al,* 2010; Sholts *et al,* 2012; Stemp *et al,* 2009). With regard to this TC based project, factors prohibiting the use of 3D technology were firstly, the expense involved in obtaining equipment of a standard high enough to enable the production of metric data and secondly, the prohibitive length of time taken to produce usable images of larger objects such as Acheulean handaxes (pers. com. Dr I.de la Torre 10/09/12). However, it was felt that with the use of 2D images and low cost or free digital imaging software, it was possible to achieve the objectives stated above, to a level of accuracy and resolution that enabled the effect of different TCPs to be tracked and analysed across multiple generations of copying.

To achieve effective area based measurements from the TC handaxe samples involved the use of ImageJ, a piece of freely available/public domain, Java-based, digital imagery software (Ferrier & Rasband, 2012). ImageJ was originally developed in the US by the National Institute of Health, for use in biomedical research and has subsequently been tailored and used in differing archaeological spheres such as Middle Palaeolithic scraper morphology (Monnier, 2007), palaeobotany (Braadbaart & van Bergen, 2005), numismatics/ancient coin measurement (Herrmann, Zambanini & Kampel, 2009) and lithic use-wear analysis (Goodale *et al,* 2012). ImageJ works by analysing digital photographs or images and calculates distances, areas and angles based on their relative pixel values. Each area required for analysis is defined by using various ‘draw tools’ and requires that a known physical distance between two defined points on the object be input into the programme, to enable it to convert pixel data to actual geometric distance and produce analysis based on an objectively created scale. Establishing the most effective methodology for achieving this scale is discussed in the following sections.

3.5.8 ImageJ methodology for planform area, cortex area and edge area

The main objective was to achieve a standardised methodology for use in inter and intra-assemblage comparisons, for both aspects of handaxe measurement as follows: firstly, area (cm^2) measurements of shape and refinement, which would allow comparison with the standard metrics and ratio analysis established by Roe (1968) and secondly, those developed as part of this thesis i.e. taper and Euclidean distance. Using ImageJ required the preparation of digital imagery of all handaxes in each TC so such analysis could be undertaken. The following sections describe the process undertaken to develop the required methodology for each aspect of measurement.

3.5.8.1 Planform area

All photographs were taken using a Nikon D90 with a Sigma Ex 50mm macro lens, mounted on a Krokus adjustable rostrum with two lights situated adjacent (at 180°) to the camera, one on the left and one on the right. The rostrum was used to provide an anchored and standardised vertical distance between the handaxe and the image plane of the camera, to aid in the scaling and consistency of each image taken; an important process as distance from camera can distort the relative size of objects being photographed with the end result of skewing measurements and therefore area calculations. This process was fine-tuned by ensuring each handaxe was positioned as horizontally as possible, by placing and adjusting different sized balls of blue tack on the underside of the handaxe until readings from a spirit level, placed as near to the centre of the handaxe as possible, along the length and width axes, indicated the handaxe was orientated as horizontally level as possible (Figures 3.16a - c). The tip of each handaxe photographed (in each TC) was also aligned with the same predefined point, as a further aid to providing a standardised horizontal orientation, helping to achieve maximum standardisation in all images taken. Camera and computer interface was controlled by Nikon Control Pro2.

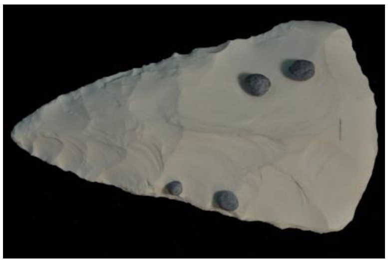


Figure 3.16a. Horizontal orientation using blue tack positioned on the underside, to level the handaxe.
Photograph: S. Page

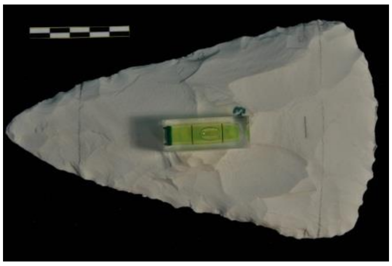


Figure 3.16b. Level positioning along length axis.
Photograph: S. Page

Figure 3.16c. Level positioning along the width axis.
Photograph: S. Page

After standardised alignment had been achieved, applied to all handaxes in Experiment 2 and photographs taken of both faces of each handaxe, it was necessary to set or establish a physical scale of measurement enabling ImageJ to convert its pixel based calculations to metrics based on centimetres and centimetres squared. The following explains the differing procedures undertaken to arrive at the most accurate way of setting that scale.

Method a

A one centimetre line (measured with a standard ruler) was drawn, in pencil, on the ventral and dorsal face of all handaxes in the TC. Each line was measured using the line tool in ImageJ. The pixel value of the 1cm line on each photograph was recorded and used to set the specific scale for calculating line distance in each photograph, of each handaxe (from which the measure was taken). Using the polygonal draw tool, the perimeter of each handaxe was traced on its photograph, defining the outline used to calculate its area in cm² (using the scale derived from 1cm line measure). This was done for each handaxe in the transmission chain represented by the cases K1, K2 etc. in Table 3.4 (below).

Results

	Ventral cm² from individual 1cm scale 1st measure	Dorsal cm² from individual 1cm scale 1st measure	+/- cm²	Ventral cm² from individual 1cm scale 2nd measure	Dorsal cm² from individual 1cm scale 2nd measure	+/- cm²
Ovate Tgt	107.23	109.71	-2.48	107.23	115.06	-7.83
TC1K1	88.59	89.06	-0.47	88.29	85.00	3.29
TC1K2	117.86	115.78	2.08	117.83	120.65	-2.82
TC1K3	115.06	124.02	-8.96	115.00	107.99	7.01
TC1K4	99.09	92.81	6.28	98.97	101.91	-2.94
TC1K5	110.63	106.97	3.66	110.70	107.37	3.33
TC1K6	114.75	112.87	1.88	114.78	118.78	-4
TC1K7	111.57	108.05	3.52	111.25	103.76	7.49

Table 3.4. Handaxe areas in cm² as measured in ImageJ using a 1cm scale taken from the face of each handaxe in TC1. K1, K2 etc. are the cases that represent the handaxe chosen by each knapper, to pass on through the transmission chain (TC1 in this case).

The outline and cm² area of each handaxe face was measured twice, to test for consistency in the measurement process. The ventral area 'first' and 'second measure' columns illustrate the process and show that in most cases, measurement was accurate to one decimal place, validating the physical measurement process. There were however two main discrepancies: the repeatability of the dorsal face measure and the difference between the dorsal and ventral face measures which as the '+/- cm²' column highlights, varied substantially between -8.96cm² and +7.49cm², not an acceptable range of difference when the average handaxe area of Ex2TC1 was 108cm². It seemed reasonable to assume that such difference was created because the 1cm scale lines could not always be drawn in the same place on the opposing face of each handaxe, due to differences in residual cortex or scar patterns and available flat areas on each face, suitable for marking. This likely created photographs where the scale bar would be at different distances from the focal plane of the camera;

thereby creating different (+/-) values for what should a standard cm measure. This type of error was likely compounded by three other factors: firstly, slight differences in handaxe alignment, which, despite best efforts to create standardised horizontal faces for each photograph, may not always be 100% possible due to the convex nature of a handaxe. Secondly, a further skewing of scale measures because the degree of convexity always varied between dorsal and ventral faces and thirdly, possible error in using the polygonal draw tool. The first attempt to overcome such problems was to create a universal pixel measure for 1cm and apply that measure to all photographs when defining the handaxe outline and area. This method is described in Method b.

Method b

A one centimetre line was drawn on the target form and measured using the line tool in ImageJ; the pixel value of that 1cm line (252) was recorded and used to create a universal scale for calculating line distance and area measures in all other handaxe photographs in that TC. Handaxe outlines were measured using the process described in the *Method a* section above.

Results

Dorsal cm² from individual 1cm 2nd measure	Dorsal cm² from universal 1cm=252 pixels	+/- cm²
115.06	115.06	0.00
85.00	93.47	-8.47
120.65	121.39	-0.74
107.99	118.18	-10.19
101.91	102.67	-0.76
107.37	117.93	-10.56
118.78	124.53	-5.75
103.76	119.14	-15.38

Table 3.5. Areas in cm² as measured in ImageJ, comparing areas produced by using a 1cm scale taken from the face of each handaxe in the TC, against areas produced by using a universal 1cm scale (from the base target form), applied to all handaxes in the TC.

Using dorsal face measures to illustrate the point, results show that not only are the second dorsal area measures, different when compared with those from the 'first measures' shown in Table 3.4, they offer no consistency at all with those obtained using a single universal scale derived from a 1cm measure marked on the target form of TC1 (Table 3.5). The key problem was not knowing which set of measures was accurate (i.e. affected the least by problems of horizontal alignment, distance from camera and being representative of the selected scale, both for the individual picture and on a comparative basis). Solving this problem required that a scale be established against a known straight line distance, specific to each handaxe and that it could be tested against another known straight line distance, before being used to calculate handaxe areas. The methodology described in *Method c* (below) addresses those issues.

Method c

Here, instead of imposing a new measure from which to create the scale, the B1 measure taken from each handaxe, as part of the metrical measures recorded for Roe's ratio based analysis, was used as the known distance from which to set the pixel-to-centimetre scale for each handaxe, on a case-by-case basis. Before that scale was used to calculate handaxe areas in cm^2, it was checked for accuracy by seeing if it would replicate the distance measure for B2, for that handaxe, obtained from the manual caliper based measure (Table 3.6). It was felt this would provide more accurate results due to the following factors.

- They were known measures of distance which could be tested against other known distances
- Each measure was edge to edge and was less affected by handaxe convexity or topography
- Greater independence from convexity and topography meant that one measure was likely to be more consistent for both dorsal and ventral faces of each individual handaxe i.e. width is the same from one edge to the next, whichever side it is measured from.

Ventral B2 fm B1 set scale fm each axe	Actual B2	Ventral total cm² from B1 set scale for each axe. M1	Ventral total cm² from B1 set scale for each axe. M2	Dorsal total cm² from B1 set scale for each axe. M1	+/- %
9.42	9.40	115.63	115.51	118.34	-2.45
7.71	7.70	95.30	95.60	94.11	1.56
8.92	8.90	123.37	123.34	121.18	1.75
8.38	8.40	115.32	115.40	113.35	1.78
8.15	8.20	102.83	102.81	101.80	0.98
8.67	8.80	115.06	115.08	117.10	-1.76
9.10	9.20	120.56	120.54	124.39	-3.19
8.75	8.80	115.59	115.35	117.74	-2.07

Table 3.6. Handaxe distance measures in cm and areas in cm², measured using ImageJ. Here the known B2 distance was reproduced using B1 to set the measurement scale with. Areas were then produced using the B1 measure for each handaxe in the TC.

The first two columns show that by using B1 to 'set scale' with, the actual or known B2 measure was, in most cases, reproduced accurately to 1 decimal place, thereby indicating the accuracy of this procedure as a measurement system. The centre columns show the consistency of the area measurement with measurement 2 (M2) being, in all cases very close to measurement 1(M1) thereby demonstrating repeatability as well as initial scale consistency. As the differences between the recorded area measures of M1 and M2 for each handaxe were close, generally down to a single decimal place, M2 was selected as the actual measure from which all subsequent calculations were made. The fifth and sixth columns illustrate further closeness i.e. an average difference of -0.43% between the ventral and dorsal area measures of each handaxe and also more consistency than produced using the 1cm set scale method shown in Table 3.4. This is due to the minimising of discrepancies in convexity, topography and scale by using the B1 measure to set scale with. To ensure this procedure was also effective using pointed handaxes, as well as ovates, it was repeated using the points of TC2 and produced comparable levels of accuracy for B2 measures and similarity of dorsal and ventral face measures (Table 3.7).

Ventral B2 from B1 set scale for each axe	Actual B2	Ventral total cm² from B1 set scale for each axe	Dorsal total cm² from B1 set scale for each axe	+/- %
8.38	8.40	104.60	102.07	2.42
8.93	9.00	99.49	99.98	-0.49
9.32	9.60	105.17	107.93	-2.62
9.38	9.30	112.47	112.90	-0.38
8.59	8.70	105.41	104.45	0.91
9.26	9.40	98.36	99.90	-1.57
9.86	10.00	104.24	103.06	1.13
8.56	8.70	86.33	84.72	1.86
8.39	8.50	90.00	90.92	-1.02

Table 3.7. Handaxe distance measures in cm and areas in cm², for the pointed handaxes of TC2, measured using ImageJ. The known B2 distance was reproduced using B1 to set the measurement scale with. Areas were then produced using the B1 measure for each axe. Results show comparable levels of accuracy with those of the TC1 ovates (Table 3.6).

This methodology was effective on two counts. Firstly, in terms of accuracy in its ability to reproduce known distances, originally achieved by using metrical points from Roe's measurement system and secondly, in its ability to replicate those measures with consistency. Success in these two areas led to the method being adopted for all planform area measures used in Experiments 2, 3 and 4. The following sections explain how that methodology was initially adopted to calculate degrees of knapping refinement by measuring handaxe edge area (or profile view) and residual cortex area, on both dorsal and ventral faces.

3.5.8.2 Edge area

The known distance acting as the basis for the edge area measurement scale was Roe's (1968) T1 measure i.e. thickness at 80% of each handaxe's length, measured from the butt – or B1 (Fig 5.1). The difficulty involved in positioning a handaxe on its edge and obtaining a consistent and symmetrical alignment, centred on the plane of intersection, where the resultant area measures would be as close as the planform measures M1 and M2 (Table 3.6), meant that when compared to the methodology used in section 3.5.8.1 (above), the edge area methodology had to be modified as follows. Each handaxe was levelled by wedging it upright in a small sample box filled with sand (the box was placed under the black photographic backdrop). Using blue-tack placed under the supporting edge, as it tapered towards the tip (Figure 3.17), the tip was raised until the bubble of a spirit level, held between the centre of the handaxe and T1, was as central as reasonably practical. This would ensure that each handaxe was as level as possible, thereby minimising scale errors due to difference in distance from the photographic plane of the camera, between one part of the handaxe and another. The degree of taper between T1 and the tip was a product of intense shaping during the knapping process and could not be compensated for in the photographic positioning process.

Figure 3.17. An edge shot of a pointed handaxe with blue tack placed under its supporting side, levelling the tip at T1 to ensure each end of the handaxe was the same distance from the photographic plane, so measurement calculations were as accurate as possible.
Photograph: S. Page

Each handaxe was photographed twice, with the rostrum set at the same, maximum height, which was necessary for consistency and also to accommodate the longest of the pointed handaxes. Due to the difficulty of symmetrical alignment centred on the plane of intersection, each photograph represented a slightly different interpretation of the closest symmetrical alignment possible. With some handaxes, where the plane of intersection, at the distal and proximal ends had been reduced quite evenly, there was little difference between the two photographs. However, for some handaxes, the plane was twisted so that distal and proximal portions appeared to have different symmetrical alignments. In cases such as these, each photographed image would be different, presenting more or less handaxe surface to the camera, thus producing cm² area figures where the difference was larger than could be accounted for by small amounts of measurement error, attributable to use of the polygonal draw tool alone. Part of this variation could be explained by the different pixel allocations (columns 3 and 5), for what was effectively the same physical distance (Table 3.8). On the basis that judging which image (and resultant area) was correct possessed a degree of subjectivity, the area from each image was averaged (column 7), to present a single, comparable figure for the edge area of each knappers' handaxe (K1, K2 etc.). In the early stages of developing the methodology, this approach appeared to offer an acceptable solution to the alignment problem.

Handaxe	T1 (cm)	Image1 - levelled Distance in pixels	Area (cm²)	Image2 - levelled Distance in pixels	Area (cm²)	+/- %	Av Edge Area
TC1 Tgt	1.8	348.00	21.34	348.00	21.65	1.45	21.50
K1	2.0	384.00	21.45	420.00	18.30	-14.69	19.88
K2	2.4	432.00	31.83	456.00	33.89	6.47	32.86
K3	2.3	444.00	28.61	438.00	28.87	0.91	28.74
K4	1.9	364.79	25.45	351.60	25.73	1.10	25.59
K5	2.0	408.00	25.73	390.00	27.13	5.44	26.43
K6	2.1	404.35	27.91	430.72	25.75	-7.74	26.83
K7	2.3	432.00	30.10	426.00	30.56	1.53	30.33

Table 3.8. TC1 ovate handaxe distance measure T1 in cm and edge areas in cm², measured using ImageJ. Here the known T1 distance was used to calculate edge areas after defining the handaxe outline using the ImageJ polygonal draw tool. The final edge area figure was produced from an average of results from two photographs, each one showing a slightly different view of the handaxe edge, due to variation in the positioning of the plane of intersection.

The initial thought was that although this measure was not as definite or objective as the measure for handaxe planform area, the edge area measurement did present a figure representative of the whole handaxe rather than a single point (such as T1) or ratio (such as $\frac{Th}{B}$) and as such, this procedure was adopted for all handaxe edge area calculations in Experiments 2 and 3. However, significant drawbacks were uncovered after the measurement of the 48 handaxes involved in Experiment 4, which accentuated the difficulty in gaining consistency of relative edge area measurement between handaxes, when multiple pieces were involved across different experiments. This stemmed from the need to position each handaxe correctly for the photograph on which the ImageJ area calculation was based. With a smaller number of handaxes i.e. the 6 chosen forms of the TC, the concern was not as pronounced and seemingly reliable data could be produced. The issue for large numbers of handaxes was caused by the problems (initially discussed above), in aligning the plain of intersection to accurately to represent the centre of the handaxe when positioned vertically on its side, allowing it to be photographed. This effectively became a subjective decision and even small movement to the left or right significantly affected the subsequent area measurement of the handaxe. This led to a situation where measurements between some handaxes were indistinguishable, when visually, there was a clear difference between them. Under these circumstances, instead of using $\frac{AEA}{ADVA}$ as a refinement measure for all handaxes, *AEA* was rejected and replaced by Roe's thickness measure (*Th*).

To create a ratio that functioned using a linear measure (*Th*) and an area based measure (cm^2) required adjustment to the *ADVA* component, to make it independent of size. On that basis the square route of *ADVA* was used, creating the ratio $\frac{Th}{\sqrt{ADVA}}$ which, was subsequently utilised to provide an alternative or complementary measure to traditional Roe (1968) based refinement measures, in all handaxe experiments.

3.5.8.3 Residual cortex area

As there were no consistency issues with planform measures, the reliable use of B1 as a known and testable distance for 'setting the scale' of planform measures of handaxe distance and area (section 3.5.8.1 *Method c*, above), was also utilised to set scale for and calculate the area of residual cortex, on both dorsal and ventral faces, of all handaxes in Experiments 2, 3 and 4. The photographs used were the same as for the total handaxe area calculations.

The areas of cortex remaining on each face are visible as the flat unscarred and slightly darker areas in each picture. If at any point it was difficult to identify these areas from the photographs, the cortical regions were outlined in pencil on the original porcelain handaxes and used as a guide in conjunction with the photographs, to accurately define the relevant areas.

3.5.9 Shape: Symmetry and the use of Flip Test

The recognition and production of artefactual symmetry, demonstrated by the archaeological record of the Acheulean, has long been positioned as marking significant points in the development of human cognitive ability (Isaac, 1986; Saragusti & Sharon, 1998; Wynn, 1985; 2002). Wynn (2002: 399) further stressed the evolutionary significance of symmetry in handaxe form by positing the idea that, as an item of hominin material culture, the handaxe could be positioned as an agent of natural selection. As part of the open peer commentary to Wynn (2002), Gurd *et al* (2002) widened the debate by asking if detection of symmetry was an innate hominin ability, or whether it derived from ecological process and was the product of recognising the frequency of environmental orientations (vertical, horizontal or oblique), which then became part of the perceptual process of shape/symmetry recognition. The putatively ingrained nature of symmetry recognition, whether innate or learned, cultural or ecological, was further discussed as being part of the human condition. Ontogenic evidence showing that infants perceive shape before they are able to produce it (in any medium) is presented as a likely indicator that Palaeolithic knappers i.e. *Homo erectus* were consciously using that perception to knap symmetrical handaxe forms; whether this is actually reflective of phylogenetic evolution is open to question.

Symmetry, per se, is a subjective concept, and handaxes said to be symmetrical have rarely been measured and their level or degree of symmetry quantified and compared. To gauge the effect of different transmission biases and relative levels of skill on handaxe symmetry, as a trait, required an unambiguous measurement procedure. The Flip Test (Hardaker & Dunn, 2005) was developed specifically to provide an objectively quantitative assessment of the symmetry present in Acheulean handaxes; the software required is available as a free download. The test is performed on a digital image of the required piece. The degree of asymmetry is calculated by rotating (or flipping) the image of the piece around its long or vertical axis; Flip Test identifies the centre of mass of the pictured handaxe (in pixels) and rotates it until the vertical axis is aligned in terms of mirror symmetry. The respective outlines formed from the pixel count of each mirror image, either side of the vertical line of symmetry, are superimposed on one another and the degree of asymmetry is calculated from the deviation presented by the flipped or rotated image from its perfect symmetry i.e. it's area, measured in pixels, if it was an exact mirror image. To take account of the size variation present in different handaxes, a scale based on pixels was created by Hardaker & Dunn (2005) using the following formula, where 'A' is the pixel count of the object's deviation from perfect symmetry and 'H' and 'W' are the respective height and width of the handaxe, expressed in pixel widths.

$$\frac{500\,(\mathrm{A})}{(H+W)^2}$$

On this basis, a multivariate measure of the handaxe is created, yielding an index of asymmetry, which allows handaxe symmetry to be compared on an inter and intra-assemblage basis. To aid analysis, Hardaker & Dunn (2005) provided an interpretation of what they perceived the differing index values to mean in terms of skill level and/or raw material quality (Table 3.9). The boundaries of each range are obviously arbitrary and could be open to adjustment with regard to qualitatively evaluating the output of each TC. In terms of assessing the effectiveness of Flip Test as a quantitative tool, Damark (2010) and Underhill (2007) provide worked examples demonstrating its robusticity as a measure of handaxe symmetry, compared with the macroscopic or by-eye method of McNabb *et al* (2004) and the polar co-ordinate and linear adjustment systems of Wynn & Tierson (1990) and Saragusti & Sharon (1998). In all cases, Flip Test provided accurate and objective results which could be produced simply and cheaply, without recourse to complicated statistical methodology. Hardaker & Dunn (2005) themselves, do however stress that Flip Test indexes and their interpretation are a guide only, requiring consideration in conjunction with other analyses and skill related measures.

Class	Index of asymmetry	Level of symmetry	Interpretation
1	1.0-1.49	Virtually perfect	Suggests an almost mathematical level of precision has been applied - unlikely on Acheulian items – could it be a modern replica?
2	1.5 - 2.99	Very high	An exceptionally skilled craftsman – special purpose?
3	3.0 - 3.99	High	Skilled work
4	4.0 - 4.99	Moderate	Average work
5	5.0 - 5.99	Low	Look for intractable material, or eccentric shape e.g. on butt.
6	6.0 & above	Very low	Look for intractable material, serious material defects, eccentric shape or a modern break in the item.

Table 3.9. Flip Test Index Interpretation (Hardaker & Dunn, 2005).

3.5.10 Identification of trends in differing TCPs

The metric attributes (dimensional, ratio and Euclidean distance) for the chosen form blades (Experiment 1), together with measures of area and symmetry for the handaxes (Experiments 2 – 4), produced by each TCP, in each experiment were plotted and graphed on a generation by generation basis, as each of the TCs progressed. To evaluate the strength of relationship, or likelihood that iterational changes in form were the result of each knapping generation, linear regression was used to fit a straight trend line through each set of data-points. That line is based on making the sum of squared residuals between each data point and the trend line, as small as possible. The coefficient of determination or resultant R^2 value is the measure of the relationship between each knapping generation, the independent variable (x) and the dependent variable, or metric attribute (y), where closeness to 1 indicates the power of the place in the transmission chain to explain changes in attribute size. The small sample sizes involved in the TCPs of this experiment (as discussed in Chapter 1 and Chapter 10), although not an ideal basis from which to evaluate trend based data, do not preclude the use of simple linear regression. If treated with this caveat in mind, regression still provides a guide to the interaction between dependent and independent variables, acting as visually helpful medium for evaluating the data. Statistical significance of the resultant trend line was assessed by a standard two tailed t-test (where the null hypothesis is that there is no trend, and that the slope of the regression is not significantly different from zero). The assumption behind the t-test is that the attribute data from each TC are normally distributed.

As each TC was comprised of multiple knapping generations, the x-axis effectively represented a time series. Where attribute data plotted against time suggest the existence of nested cycles, this raises the problem of autocorrelation (where there are lagged effects of a value at one time step, on values at a more distant subsequent time step). However, where sequences are short, between 5 and 8 generations or data points, as is the case for the TCs in this research, it is not deemed a problem. This is because it is difficult to detect meaningful examples of autocorrelation, related to residual variation, in small sample sizes (DeCarlo & Tryon, 1993). More recently, Müller (2014) strengthened the case for using linear regression in short time based sequences by stating that correcting the effect of autocorrelation in small sample sizes, where typically $n = <50$, is ineffectual.

The case for linear regression is further strengthened by the presence of extensive evidence of its use in situations where time sequences are more extended and where there is likely to be lagged autocorrelation in the dependent variable. A notable and recent example is the case of measuring long-term trends in climate change (Prior & Perry, 2014). Here, warmth, through a cycle of seasons would have built up on a cumulative basis, just as knapping variation may have built up on a cumulative basis. The difference here was not in the use of simple linear regression, but in the testing of the significance of the slope by using the non-parametric Mann–

Kendall tau test (Sneyers, 1990), as opposed to a standard *t*-test for parametric data. In this case it was assumed that data was not behaving normally.

To test the appropriateness of correlation coefficients and significance testing derived from linear regression in this thesis, Appendix 1 compares all results where $R^2 > 0.5$ with those derived from using the Mann-Kendall tau test. Here, the ranks of each observation are used instead of their actual values (rank correlation), and the strength of dependence between x and y variables is based on the tau coefficient (τ) rather than R^2. Appendix 1 shows that in the majority of cases results are quite similar, however, in cases marked ***** in the 'Change' column, results have moved from significant to non-significant, indicating that a parametric approach can misinterpret the presence of a trend and attribute significance that may not actually exist. These issues will be highlighted in any future publication of results.

With this in mind, it should be noted that in the case of the TCPs in this thesis, there are two factors, both of which relate to the caveats that should be considered when sample sizes are small. Firstly, the fitting of a straight regression line does ignore non-linear curve shapes, which may reveal interesting patterns in the data, such as the influence of specific short term copying/transmission phenomena. However, with TCs varying between only 5 and 8 generations or data points, it is difficult to see any reliable meaning being gleaned from a non-linear curve when the whole data sequence is so short. The Second point relates to how low numbers of data points may not be able to produce enough power to accurately test or overturn the null hypothesis, which raises the issue of how useful a *p*-value provided by a standard *t*-test, as used in this research, is likely to be. In this respect, the nature of this research is governed by the limitations created by the small sample sizes and as such, use of the coefficient of variation and of subsequent significance tests has to be treated with caution as a means of refuting hypotheses about the effects of copying on artefact form. It is likely, that with larger sample sizes, it would have been possible to detect further effects of transmission generation on directional change in artefact forms – effects that are discounted by the tests conducted here. A failure to achieve statistical significance, in such small samples, should be taken to mean that the hypothesis was not supported in these particular experiments, and not as proof that the hypothesis itself is definitively incorrect.

3.6 Conclusion

The procedures covered by this chapter explain the development of methodological solutions, designed to minimise extraneous sources of variation in the production and measurement of lithic artefact forms. The problems created by heterogeneous raw material and a paucity of appropriately skilled knappers are relevant to most experimental studies of archaeological lithic technology but carry particular importance in the context of transmission chain protocols. As the objectives of this study are to examine the cumulative evolution of artefact form as a result of skill differential, transmission biases or perceptual limitation, any variation attributable to deficiencies in raw material homogeneity or misallocation of skill level will have a compound effect on artefacts as they pass through the multiple generations of a transmission chain and are therefore minimised as much as is reasonably practicable. With the objectives of the thesis focused specifically on change and variation in the final artefact form, in a culture evolutionary sense, emphasis was not placed on the quantity or quality of individual flake removals or waste. In this respect, the approaches covered by Chapter 3 have been applied and adapted to the experiments outlined in the following chapters, which will explore issues related to change solely in artefact form during the transmission of two different Palaeolithic technologies: blade production (Experiment 1) and Acheulean handaxe manufacture (Experiments 2 - 4).

The basic structure of the experimental programme is outlined in Table 3.10, illustrating how the TCPs and materials developed for the project were applied to each experiment, together with a column showing the final output of each TC. Also shown here are the number of archaeological handaxes, by site/assemblage for Boxgrove, Cuxton and Tabun used for comparison with the experimentally produced material, which forms part of the comparative discussion presented in Chapter 9.

Assemblage	TCs	Generations	TCP	Technology	Preform cores	Final artefacts
Experiment 1	TC1	6	Unaided end-state copying	Blade	12	236
	TC2	5	Unaided end-state copying	Blade	10	163
Experiment 2	TC1	7	Unaided end-state copying	Ovate handaxe	14	11
	TC2	8	Unaided end-state copying	Pointed handaxe	16	14
Experiment 3	TC1	7	One-to-one expert instruction	Pointed handaxe	14	12
Experiment 4	TC1	6	Many-to-one peer instruction	Pointed handaxe	48	48
Boxgrove	-	n/a	-	Pointed handaxe	n/a	24
Cuxton	-	n/a	-	Pointed handaxe	n/a	19
Tabun	-	n/a	-	Pointed handaxe	n/a	85

Table 3.10. Basic summary of materials and methods used in the experimental programme together with those from the archaeologically produced assemblages.

Chapter 4 (the following chapter) presents the results from the blade based TCs of Experiment 1. Before each of the three handaxe experiments is dealt with and compared with suitable archaeological assemblages (see Table 3.10), Chapter 5 discusses other attempts to capture variation in handaxe morphology, helping to situate Roe's (1968) system. It then presents these methodologies within the wider context of how they each explain variation in Acheulean handaxe form, but within the broader framework of long-term stasis, before it presents the objectives of each individual experiment and the contribution that the culture evolutionary approach can make.

Chapter 4.

Exploring variation in lithic form in transmission chains. Experiment 1: the effects of skill level and perceptual biases on copying blade forms.

4.1 Introduction

This experiment is the first in a series seeking to combine elements of research conducted in experimental psychology, with those conducted in experimental archaeology. Whilst the effects on artefact design features of successive ‘generations’ of copying in a transmission chain have been investigated in psychology (Eerkens, 2000; Evans, 1875; Griffiths *et al,* 2008; Mesoudi & O’Brien, 2008a; Ward, 1949), no multi-generational work examining copying error as a product of cultural transmission has been conducted using an archaeologically attested technique such as stone knapping. Conversely, in archaeology, the concept of artefact variation as the product of differential skill levels and of transmission techniques has been explored experimentally by comparing groups of differing ability, but only by examining changes after a single bout of copying (Bril *et al,* 2010; Geribas *et al,* 2010; Nonaka *et al,* 2010; Shelly, 1990; Williams & Andrefsky, 2011). However, artefact variation has not been explored using the cumulative, multi-generational TCP research designs that are increasingly common in experimental psychology.

The knapping task explored by Experiment 1 was been designed to reflect the issues involved in managing the conchiodal dynamics of blade removal. As discussed in Chapter 2 (section 2.1.2), this process involves understanding the relationships between force and velocity of strike, angle of strike, platform depth and exterior platform angle (Bril *et al,* 2010; Dibble & Rezek, 2009; Nonaka *et al,* 2010). It also requires possession of the relevant level of sensory-motor control necessary to execute the action effectively. All knappers participating in the experiment had to reach the minimum level of ability required to perform the task, in accordance with the skill level of their allocated TC, as described in section 3.4.1. Even for a task whose execution is comfortably within the abilities of the subjects, it was expected that copying errors, caused by universal psychological limitations would cause the copies to drift away from the target form (Eerkens & Lipo, 2005). However, the *rate* of change in artefact form along each transmission chain was expected to be influenced by the skill level of the knappers comprising that chain. Transmission chain 1 (TC1) contained the more skilled knappers, scoring three or above in the skill assessment, with the second transmission chain 2 (TC2) containing knappers possessing lesser skill levels, who scored below three in the skill assessments (Table 3.2). As effective performance in a reductive technology such as stone knapping requires relatively high levels of knowledge and skill, it was expected that errors in the reproduction of the finished artefact form, even in quite short single member chains would give rise to significant variation between the base target form or initial ‘model’ and that produced by the final chain member. It was hypothesised that the TC with the more skilled members would achieve greater copying fidelity based on their superior ability to imitate the knapping techniques originally learnt from their expert instructor. However, due to the complexity of the biomechanical and cognitive skill-sets involved in the knapping process, emulation (as opposed to direct imitation) of what the knappers considered to be the correct knapping process to produce the target form i.e. end-state copying (Caldwell *et al*, 2012) would likely result in lower levels of fidelity and incoherent transmission.

4.2 Objectives

The overarching objective of the larger set of experiments for this thesis is to examine the effect of different transmission chain protocols (TCPs) on lithic artefact form. Within that objective, the two main aims of Experiment 1 were:

- To ascertain the effect of skill level on transmitted levels of variation within each transmission chain (TC). This was differentiated by having TC1 comprised of more expert knappers and TC2 of novice or intermediate knappers. It was expected the outcome of this would likely illustrate that differences in artefact attributes often allocated to function, style, raw material etc. may, in fact, be a direct result of differences in skill level over and above levels of random drift caused by human psychological/perceptual factors.

- To identify recurrent patterns in the form of copied artefacts as they diverged from the original target model. It was expected that, in line with the Weber fraction and caused by universal perceptual limitations in ability to reproduce artefact dimensions (Eerkens, 2000), the form of copied artefacts would drift away from that of the target artefact and there would be a change in size between the first and last iterations. Such changes could be significant enough to create a seemingly distinct, but false typological class.

4.2.1 Target form

The target lithic form chosen for both TCs of Experiment 1 was a blade 4cm long, 1cm wide, 0.3cm thick, weighing 1.4g with a single central dorsal ridge and parallel edges (Figure 4.1). This particular form was chosen because of its relatively simple and standardised morphology but one that never-the-less would be subject to stylistic drift caused by human perceptual limitations. The random nature of such drift and the potential that knapping skill has to affect that process is highlighted by the fact that successful blade production requires the same, consistent knapping intention throughout the sequence of the entire blade making process. To serially produce blades with the same morphology, requires what Sørensen (2006: 292) describes as a technologically consistent approach covering not only the hammerstone or other knapping tools but also the morphology of the core, the trimming or scrubbing to prepare for each blade and the force and angle of each strike designed to remove the blade. To achieve this, Sørensen goes on to state there has to be an intention that visualises what the ideal blade is. In this context, the ideal blade is the target form of Experiment 1 (described above). The factors that cause morphology to drift from that ideal form are, as discussed, likely to be a product of human psychological limitations and differences in the level of skill required to achieve the desired form, on a systematic basis.

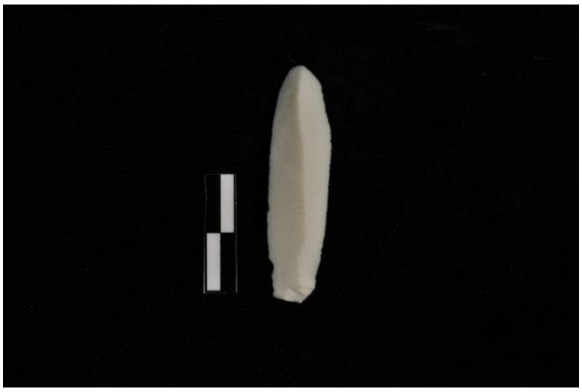


Figure 4.1. Base target form blade for TC1 and TC2.
Photograph: S. Page

4.3 Methodology

4.3.1 Transmission Chain Protocol

Members of the knapping cohort were split into two groups. This division was dependent solely on their performance in the skill assessment exercise (section 3.4.1) and resulted in the following division: for TC1, the more skilled group, n= 6; for TC2, the less skilled group, n=5. The first member of each TC received the same 'target' artefact form to copy. Both TCs functioned as follows: the knapper in Generation 1 received the original target form (prepared by the experimenters) to reproduce. Following that, each subsequent generation received the 'best copy' produced by the previous knapper or generation, as his/her target form.

In each generation (or bout of copying) the knapper was given two previously prepared standardised porcelain preform cores (section 3.2.3) and was asked to produce as many copies of the target form as possible. They were told to examine their target form and replicate its shape, all dimensions (length, width, thickness) and surface morphology (ridge/scar patterning) as closely as possible. To aid this process, the target form of each iteration was viewable by the knapper for the entire duration of the session, as the objective was to examine copying ability as opposed to memory retention. Every knapper in both chains used the same hammerstone, an elongated piece of soft, limey sandstone, weighing 152.2 grams. For this experiment there was no specified time limit and each knapper could move from the first to second preform core or stop knapping when they felt the target form could no longer be produced from the core remaining. After the bout, the knapper was asked to choose the piece they considered best matched their ‘target’ form. That piece was then passed on to the next knapper in the TC as his/her target form. In each instance, that choice was verified independently by the experimenters. It was expected that the knapper choices would differ from those of the experimenters, leading to differences in perception of reproduced form but in all cases, the choices made were the same. The specification of the original target form (section 4.2.1) as knapped by BB, was the same for both TCs.

As part of the recording system, each flake/blade removal for each knapping bout was sequentially recorded as it was detached from the core but was not marked until after both the knapper and the experimenter had judged which removal was the closest match to the target form. In this way, information on the labelling of the knappers’ output did not ‘contaminate’ the independent experimenter’s judgement as to what he/she thought the closest match to the target form was. It is also important to note that before the knapping bouts, apart from the knapping instructions specific to copying the target form (as specified in the previous paragraph), the subjects did not receive any indication of the specific nature and purpose of the experiment. In the same way, after their bouts, subjects did not meet to ‘compare notes’ within or between TC groups and did not discuss the experiments within the hearing of subjects who had not had their turn. This procedure was designed to ensure that the output of the TCs was subject to as little external bias or influence as possible. After labelling, the knapped output of each participant was measured according the process outlined in Chapter 3 (methodology section 3.5.1).

4.3.2 Statistical methodology and analysis

To fulfil the objectives stated in section 4.2, the specific research questions addressed by Experiment 1 were as follows:

- Is it possible to identify the effects on lithic variation of differing levels of skill?
- Is it possible to identify the effects on lithic variation of perceptual limitations?
- Is it possible to track and account for the cumulative or evolutionary effects of such variation as it passes through multi-generational transmission chains?

Statistically testing and differentiating the effects on lithic variation of inconsistency of ability, stylistic drift and of idiosyncratic change is an area where there appears to be little standardised procedure. In addressing the above questions, the approach used in this analysis adapts and applies techniques used in analogous studies in lithic technology and studies of variation in other archaeological crafts. In this respect, the objective is to develop a series of procedures that enable comparison and quantification of variation in both metric and non-metric attributes through multiple generations of reproduction of lithic form. For each TC, metric and non-metric variation was examined on two levels, firstly within and between the assemblages produced by each knapper, as a measure of their relative skill and consistency. Secondly, for each TC, the attribute variation present in the blade-form selected and passed through the chain as the target form for each subsequent knapper in the TC, was examined from the perspective of focusing on change in artefact form as a result of multiple generations of copying.

Differing methods of analysis were used to detect the random or directional changes in assemblages and the form of target artefacts along each TC, and were applied as follows. As changes in form were expected to deviate within and between assemblages, according to either skill level or perceptual limitation, standard deviation for each metric attribute was used to examine inter-assemblage variation from the mean. To allow for effective comparison of variation between groups, the coefficient of variation (CV) was used for evaluation of the metric data. New methodology was developed using the basic metric data to produce more inclusive measures of form change. For blade shape, a measure of length adjusted taper was introduced. To provide an indication of 3D change in form, a measure of Euclidean distance was developed to measure the 3D distance travelled, by each chosen blade, from the base target form (see methodology sections 3.5.2 and 3.5.4 for formula and details of all these techniques). With regard to discrete features, it was hypothesised that achievement by level of skill would be different for each variable and also that the combinations in which variables would be achieved would also be different. On this basis, analysis of co-occurrence was used to examine patterns of change in discrete features on an inter-generational basis. With regard to the type or strength of relationship between the knapper and their output, it was hypothesised that all variables or attributes would behave in the same way and there was an expectation that in the more skilled group (TC1) there would be less random variation. To assess the strength of relationship for the variability of form within and between each chosen target form and set of copies in each transmission chain, linear regression was used to measure the coefficient of determination (R^2). To test the statistical significance of results, *t*-tests, Levene's test, Chi^2 and the *p*-values generated from each respective analysis were also carried out as appropriate. The techniques highlighted here are described more fully in the following sections.

Issues of raw material variation affecting the output of each knapper and each TC in Experiment 1 were neutralised by the use of the standardised, pre-prepared core forms (section 3.2.3). With this external factor removed, using the CV allows comparison of metric attribute variation within and between assemblages, as explored by Roux (2003) in her study of potters (again, see section 3.5.2 for detail). This methodology translates directly to measuring lithic variation produced in transmission chains where the objectives are to quantify variation in metric attributes, between individual knappers and between the two TCs. Disparity in CV between the assemblages produced by each generation of the TCs, where TC generation was the independent variable (*x*) and attribute CV the dependent variable (*y*), was tested by using linear regression, performed using Microsoft Excel (2010). The causal strength of the relationship between the two variables (CV and TC generation) was evaluated by R^2 and the likely significance of subsequent trends generated by the data points, by the *p-value* for each data-set. Differences were then assessed in relation to alternative hypotheses of possible causes (drift/perceptual limitation or skill).

The CV offers its most meaningful results when calculated on a per knapper basis for attributes of a one-dimensional nature. Despite the advantages of standardisation and constancy provided by the CV, when comparing inter and intra-assemblage variation amongst the metric variables produced by each knapper, problems of non-comparability of CV values occur when comparing variation in one linear dimension with variation in an area (2D) or volume (3D) measure. Thus, Table 4.1 demonstrates that for weight, CV values ranged between 56.98% and 100.54%. Such high CVs were produced because weight operates as a measure of volume, thereby acting as a multiplier for the three separate dimensional measures of length, width and thickness (a solid object will double its volume when each of its three dimensions increases by only 25%). To draw accurate or statistically significant conclusions from the use of the single attribute CVs, such as those presented in Table 4.1 in combination with the linear trend (R^2) charts (Figures 4.2 & 4.3), required exploring the variation between pairs of attribute CVs, by using Levene's test. Levene's test is a 2-tailed t-test, which assesses equality of variance between groups, knapper assemblages in this case, against a null hypothesis that variances for a given attribute were equal. Where the resulting significance rating or *p-value* was less than 0.05, it was concluded the difference between the groups was genuine and not the product of random variation. All operations involving Levene's test were conducted using SPSS version 21.

4.3.3 Analytical procedure for non-metric data: analysis of co-occurrence

In addition to replication of the metric dimensions of target form, the other key measures of lithic form are the discrete traits or non-metric attributes (section 3.5.1). In Experiment 1, those traits centred around achievement of a certain pattern of ridges on the dorsal face of the blade, and the overall shape of the blade (i.e. whether it had parallel edges, was convergent or was a point form). Initial analysis focused on achievement of single attributes, however, as a measure of knapping skill and consistency, the ability to produce both the desired ridge pattern and blade shape, in combination, is a key factor. This was analysed by the production of a co-occurrence matrix and examined by knapper, for each of the TCs. As well as highlighting differences in skill level, use of co-occurrence matrices also provided an insight into how achievement of each target form eventually broke down through the generations of the transmission chain.

4.4 Results

4.4.1 Metric attribute variability by TC and assemblage

Preliminary inspection of Tables 4.1 and 4.2 gave the overall impression that the knappers in TC1 were more efficient in reducing their cores than the knappers in TC2: in TC1, each knapper produced an average of 43 flakes of more than 20mm length, with an average assemblage weight of 117g, while in TC2, the averages were 34 flakes and an 81g assemblage weight. Running *t*-tests (two sample, assuming unequal variances) on the data in table 4.2, against a null hypothesis that there was no significant difference between the results of the two TCs yielded the following results: for ‘number of blades’, *t* stat = 1.46; *t* critical (2 tail) = 2.26; *p*-value = 0.178 meaning no significant statistical difference. However, for assemblage weight (based on pieces where length > 2cm), *t* stat = 3.85; *t* critical (2 tail) = 2.26 and for ‘blade length’ *t* stat = -1.90; *t* critical (1 tail) = 1.89. In both cases, the *t* stat was higher than the *t* critical value and in both cases the *p* value was less than 0.05 indicating that differences in efficiency of reduction between the two TCs were statistically significant. On this basis, in terms of the reduction hypothesis, more of the original core weight was contained in the blade assemblage of the TC1 knappers and less in the exhausted core and debitage, when compared to the knappers of TC2, meaning that overall, TC1 knappers were reducing their cores more efficiently than TC2 knappers.

Despite the disparity in skill levels on which each TC was constructed, with the more skilled knappers in TC1 and less skilled knappers in TC2, the average CVs did not behave in accordance with hypothesised expectations. Firstly, levels varied and were not the same for each attribute and secondly, the level of difference between TC1 and TC2 did not appear to reflect the higher levels of skill possessed by TC1, that is, width and weight varied little between the two chains, whereas length and thickness did (Table 4.1). The first significant difference came when looking at the CV for knapper blade length using a one-tailed *t*-test; the single tail was used in preference to a two-tailed test because the focus was solely on there being less or lower levels of variation in TC1. In TC1, against a null hypothesis that TC1 blades displayed no difference compared to those of TC2, the *t* critical value of 1.89 was less than the *t* stat of 1.91 and the *p* value of 0.049 marginally less than 0.05, indicating that there was a difference i.e. the lower levels of length CV for the assemblages of TC1 blades was significant (just), when compared to that of TC2. In this respect, the skill differential was having an effect on blade metrics.

The two hypotheses that firstly, CV levels would be the same for each attribute (according to their TC) and secondly, that the level of difference between TC1 and TC2 would reflect the higher levels of skill possessed by TC1, continued to be explored. Initial analysis of the data comparing all metric CVs demonstrated that contrary to expectation, CV levels for each attribute were clearly different, with the smallest dimension (thickness) possessing higher levels of CV than the larger dimensions of width and length respectively (Figures 4.2 & 4.3). With regard to intra-group performance, TC1 possibly had a more uniform level of skill among its knappers; Figure 4.2 and 4.3 illustrate that the CVs for the lesser skilled TC2 tend to be more erratic, particularly for thickness and weight. The flatter or less erratic lines of the TC1 group all displayed R^2 values indicating a moderate statistical relationship between each attribute CV and the knapping generation, pointing towards more uniform levels of knapping on an inter-generational basis, in comparison with TC2.

TC&Knapper		Length (mm)	Width (mm)	Thickness (mm)	Weight (g)
Average all	CVs	18.72	30.30	54.51	77.86
Average TC1	CVs	17.49	30.01	51.94	77.89
Average TC2	CVs	20.19	30.64	57.59	77.83
TC1K1	N	34	34	34	34
	Mean	34.71	14.18	4.62	2.62
	Std.Deviation	6.75	3.77	1.72	1.70
	CV (%)	19.45	26.59	37.33	64.89
TC1K2	N	44	44	44	44
	Mean	37.68	14.23	4.70	3.07
	Std.Deviation	4.77	3.21	1.95	1.67
	CV (%)	12.65	22.53	41.41	54.40
TC1K3	N	30	30	30	30
	Mean	36.73	15.60	5.50	3.90
	Std.Deviation	5.71	4.51	2.39	3.07
	CV (%)	15.55	28.89	43.43	78.72
TC1K4	N	51	51	51	51
	Mean	35.14	12.71	3.98	2.44
	Std.Deviation	6.15	4.36	2.35	2.37
	CV (%)	17.52	34.35	58.92	97.13
TC1K5	N	41	41	41	41
	Mean	35.29	13.95	4.12	2.88
	Std.Deviation	6.34	4.82	3.02	2.48
	CV (%)	17.96	34.56	73.22	86.11
TC1K6	N	58	58	58	58
	Mean	33.60	11.88	3.76	2.03
	Std.Deviation	7.33	3.93	2.15	1.66
	CV (%)	21.80	33.12	57.33	81.77
TC2K1	N	46	46	46	46
	Mean	30.85	12.39	3.20	1.56
	Std.Deviation	6.35	4.22	1.59	1.28
	CV (%)	20.58	34.09	49.64	82.05
TC2K2	N	34	34	34	34
	Mean	35.91	13.09	4.68	2.47
	Std.Deviation	6.41	3.14	1.80	1.52
	CV (%)	17.84	23.97	38.58	61.54
TC2K3	N	30	30	30	30
	Mean	36.53	14.60	5.33	3.56
	Std.Deviation	7.58	4.63	3.04	3.04
	CV (%)	20.76	31.70	57.07	85.39
TC2K4	N	20	20	20	20
	Mean	38.95	14.90	6.20	3.69
	Std.Deviation	8.21	5.42	6.29	3.71
	CV (%)	21.08	36.36	101.42	100.54
TC2K5	N	40	40	40	40
	Mean	31.40	12.45	3.43	1.72
	Std.Deviation	6.50	3.37	1.41	0.98
	CV (%)	20.71	27.10	41.23	56.98

Table 4.1. Analysis, by knapper, of standard deviations and CVs produced by metric attributes from TC1 and TC2.

TC	Knapper	Blades per assemblage	Av. Blade wt. (g)	Assemblage blade wt. (g)	Blade length CV
1	1	34	2.62	89.08	19.45
1	2	44	3.07	135.08	12.65
1	3	30	3.90	117.00	15.55
1	4	51	2.44	124.44	17.52
1	5	41	2.88	118.08	17.96
1	6	58	2.03	117.74	21.80
2	1	46	1.56	71.76	20.58
2	2	34	2.47	83.98	17.84
2	3	30	3.56	106.8	20.76
2	4	20	3.69	73.8	21.08
2	5	40	1.72	68.8	20.71

Table 4.2. Transmission chain summary data for each assemblage, by knapper

It is not entirely clear why the latter generations in the TC produced more variation than the earlier generations but reference to the chosen forms in Figure 4.4 shows that the knapping task was probably becoming more difficult as the target blade form changed and notably became much wider. Against a null hypothesis that skill and/or drift would have no effect on blade form, *p*-values of 0.048 and 0.042 for width and thickness respectively, also indicated moderate statistical evidence in favour of the alternative: that level of knapping skill within the TC, or more relevantly, lack of knapping skill, was affecting these two variables and was responsible for the upward trends in width and thickness CV as the transmission chain progressed. All R^2 and *p*-values for TC2 showed no strength of relationship or statistical significance, perhaps indicative of the greater effect of randomness created by the lower levels of skill present in that TC (Figure 4.3).

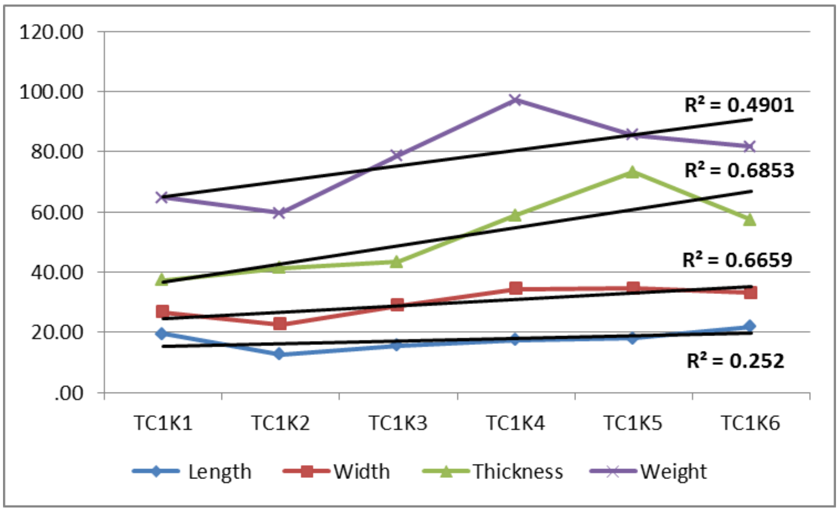


Figure 4.2. TC1 Metric attribute CVs by knapper and subsequent attribute R^2 values (Length, p = 0.31; Width, p = 0.048; Thickness, p = 0.042; Weight, p = 0.12).

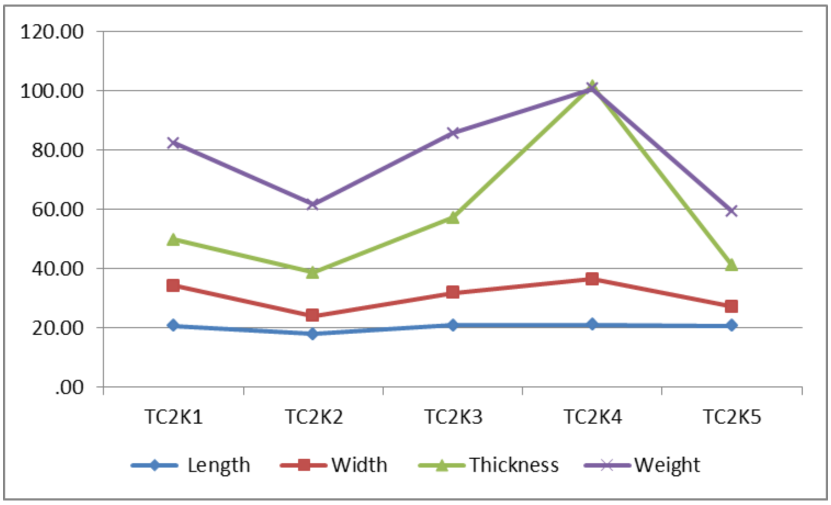


Figure 4.3. TC2 Metric attribute CVs by knapper. R^2 and *p- values* showed no strong or significant relationships were registered between attribute and TC knapping generation.

The CVs by attribute produced by each knapper in TC1 tended to operate within a range of variance on a statistically significant upward trend, excepting length (Figure 4.2); likely the result that some knappers were worse at controlling certain variables than others. To test for intra-chain differences in knapper skill level, 2 tailed *t*-tests were used for comparison of mean variance in CV levels. The significance of the CV *p*-values between different pairs of knappers was then evaluated using Levene's test for equality of variance between pairs of data. Table 4.3a presents the mean data in a matrix where levels of significant difference ($p < 0.05$ and 0.05 - 0.10 for moderate significance) between each pair of knappers are highlighted in blue. The analysis revealed that knapper 2 was consistently, for 4 out of 5 pairings, producing a statistically significant longer mean blade length than the other knappers in the TC. When combined with Levene's test (Table 4.4a) the length of knapper 2's blades also had a statistically significant lower range of variation in 3 out of 5 pairings. This level of performance verified the possession of higher skill levels linked to regularly producing blades that were consistently longer than the other knappers.

	TC1					
Knapper	1	2	3	4	5	6
1	-	0.034	0.202	0.799	0.749	0.437
2	0.034	-	0.446	0.026	0.044	0.001
3	0.202	0.446	-	0.231	0.294	0.038
4	0.799	0.026	0.231	-	0.925	0.231
5	0.749	0.044	0.294	0.925	-	0.236
6	0.437	0.001	0.038	0.231	0.236	-

	TC2				
Knapper	1	2	3	4	5
1	-	0.001	0.001	0.000	0.708
2	0.001	-	0.797	0.133	0.004
3	0.001	0.797	-	0.257	0.005
4	0.000	0.133	0.257	-	0.000
5	0.708	0.004	0.005	0.000	-

Table 4.3a & 4.3b. Equality of means between knapper CV levels for blade length in TC1 (a) & TC2 (b). Significant differences between relevant pairs are highlighted .

	TC1 Length					
Knapper	1	2	3	4	5	6
1	-	0.014	0.141	0.363	0.473	0.364
2	0.014	-	0.523	0.111	0.092	0.000
3	0.141	0.523	-	0.469	0.410	0.013
4	0.363	0.111	0.363	-	0.874	0.041
5	0.473	0.092	0.410	0.874	-	0.080
6	0.364	0.000	0.013	0.041	0.080	-

	TC2 Length				
Knapper	1	2	3	4	5
1	-	0.972	0.244	0.362	0.915
2	0.972	-	0.273	0.393	0.945
3	0.244	0.273	-	0.968	0.300
4	0.362	0.393	0.968	-	0.420
5	0.915	0.945	0.300	0.420	-

Table 4.4a & 4.4b. Levene's equality of variance between knapper CV *p*-value levels for blade length in TC1 (a) & TC2 (b). Significant differences between relevant pairs are highlighted in blue.

By contrast with the tight performance of knapper 2 in TC1 (discussed above), knapper 6 of TC1 was less able to control length than any other knapper, a low mean length of 33.6mm and high standard deviation of 7.33mm (Table 4.1) was supported by 2 significant mean length differences (between K6 and K2 and

K3), that didn't occur for any other knappers in the TC (Table 4.3a). In terms of equality of variance, knapper 6 also displayed a wider range of variation in four out of five cases, when compared to the other knappers in the chain (Table 4.4a). For the lesser skilled TC2, knappers 1 and 6 displayed significance for producing blades with a consistently low mean length compared to the other knappers (Table 4.3b). For equality of variance measured by Levene's test (Table 4.4b), there were no significant relationships at all, likely displaying the causal link between higher degrees of randomness and lower levels of skill.

For blade width, in TC1 the only individual who stood out positively when considering the significance of CV scores for mean width (Tables 4.5a & 4.5b) was knapper 6 of TC1, whose mean blade width (11.88mm) was significantly lower than the other TC1 knappers in 4 out of 5 cases (Table 4.5a). However, when looking at the range of variance, the ability of knapper 6 to knap a consistent blade width, as measured by Levene's equality of variance, was only significantly different from one other knapper (knapper 5) (Table 4.6a). When considering TC2, knapper 2 had the lowest width CV of all knappers, in both chains (17.84) but for only 34 blades (Table 4.1). He/she also produced significantly less width variance when compared to three of the four other TC2 knappers (Table 4.6b). For blade width, this was a good knapping performance and when evaluated in conjunction with a mean width of 13.09mm, it indicated that in terms of maintaining a consistently narrow blade, knapper 2 of TC2 was performing better than most of the TC1 knappers.

	TC1 Width					
Knapper	1	2	3	4	5	6
1	-	0.923	0.165	0.138	0.935	0.012
2	0.923	-	0.131	0.068	0.859	0.003
3	0.165	0.165	-	0.007	0.175	0.000
4	0.138	0.068	0.007	-	0.181	0.321
5	0.935	0.935	0.175	0.181	-	0.02
6	0.012	0.003	0.000	0.321	0.02	-

	TC2 Width				
Knapper	1	2	3	4	5
1	-	0.437	0.040	0.047	0.975
2	0.437	-	0.147	0.124	0.402
3	0.040	0.147	-	0.824	0.030
4	0.047	0.124	0.124	-	0.070
5	0.975	0.402	0.030	0.070	-

Table 4.5a & 4.5b. Equality of means between knapper CV levels for blade width in TC1 (a) & TC2 (b). Significant differences between relevant pairs are highlighted in blue.

Knapper	1	2	3	4	5	6
1	-	0.328	0.524	0.333	0.092	0.861
2	0.328	-	0.121	0.037	0.005	0.213
3	0.524	0.121	-	0.860	0.394	0.579
4	0.333	0.037	0.860	-	0.400	0.364
5	0.092	0.005	0.394	0.400	-	0.086
6	0.861	0.213	0.579	0.364	0.086	-

Knapper	1	2	3	4	5
1	-	0.096	0.594	0.278	0.107
2	0.096	-	0.045	0.019	0.971
3	0.594	0.045	-	0.581	0.055
4	0.278	0.019	0.581	-	0.025
5	0.107	0.971	0.055	0.025	-

Table 4.6a & 4.6b. Levene's equality of variance between knapper CV levels for blade width in TC1(a) & TC2(b). Significant differences between relevant pairs are highlighted.

With regard to the hypothesis that in each TC the level of variation or CV would be the same for each attribute, of specific interest were the CVs for thickness, which were repeatedly higher than those of length and width (Figures 4.2 & 4.3). This was likely a function of the consistent level of accuracy required to strike the core at the appropriate distance from edge and at the correct angle to serially produce blades of a specific thickness. This is perhaps one of the most difficult aspects of blade knapping to master, as illustrated by the generally higher CV levels of the lesser skilled knappers of TC2 e.g. knapper 4, whose standard deviation of 6.29mm was greater than their mean width of 6.2mm, resulting in a CV of 101.42. The thickness CV of knapper 2 in the more skilled TC1 was 41.41, which, together with the ability to produce long blades (44) with a low CV value, again displayed evidence of the higher levels of consistency he/she possessed compared to the other knappers (Table 4.1, 4.3a and 4.3b). However, when examining solely the thickness performance of knapper 2 (TC1), there was no statistically significant difference between the mean CV values or the range or equality of that variance (from Levene's test) relative to the other knappers of TC1 (Tables 4.7a & 4.8a). For knapper 2 of TC2, the positive performance in producing consistency of blade width (discussed above) was also carried into knapping thin blades; whilst not producing the lowest mean thickness, knapper 2's range of thickness, from Levene's equality test, showed significantly less degree of variation when compared to 3 of the 4 other knappers in the chain. The equality of variation in all TC2 thickness CVs (Table 4.8b) recorded statistically significant differences either positively or negatively between all pairs of knappers excepting 1 & 2 and 1 & 5. This is an unusual situation and again points to randomness of performance between each of the TC2 knappers, likely linked to wide disparities in their respective levels of skill.

	TC1 Thickness					
Knapper	1	2	3	4	5	6
1	-	0.820	0.117	0.189	0.407	0.055
2	0.820	-	0.156	0.112	0.290	0.026
3	0.117	0.156	-	0.010	0.052	0.001
4	0.189	0.112	0.010	-	0.808	0.612
5	0.407	0.290	0.052	0.808	-	0.494
6	0.055	0.026	0.001	0.612	0.494	-

	TC2 Thickness				
Knapper	1	2	3	4	5
1	-	0.000	0.001	0.049	0.486
2	0.000	-	0.301	0.315	0.001
3	0.001	0.301	-	0.542	0.001
4	0.049	0.315	0.542	-	0.067
5	0.486	0.001	0.001	0.067	-

Table 4.7a & 4.7b. Equality of means between knapper CV levels for blade thickness in TC1 (a) & TC2 (b). Significant differences between relevant pairs are highlighted.

Knapper	1	2	3	4	5	6
1	-	0.208	0.202	0.070	0.080	0.077
2	0.208	-	0.660	0.403	0.254	0.539
3	0.202	0.660	-	0.821	0.553	0.996
4	0.070	0.403	0.821	-	0.590	0.758
5	0.080	0.254	0.553	0.590	-	0.414
6	0.077	0.539	0.996	0.758	0.414	-

Knapper	1	2	3	4	5
1	-	0.289	0.009	0.000	0.519
2	0.289	-	0.086	0.004	0.097
3	0.009	0.086	-	0.071	0.004
4	0.000	0.004	0.071	-	0.000
5	0.519	0.097	0.004	0.000	-

Table 4.8a & 4.8b. Levene's equality of variance between knapper CV levels for blade thickness in TC1(a) & TC2(b). Significant differences are highlighted.

The disparities discussed above, provide further indication of the knapping difficulty in managing multiple dimensional attributes simultaneously and consistently. The difference in CV values showing significant levels of equality of variation, again illustrates the apparent difficulty of controlling the sensory-motor dynamics involved in the knapping process, to enable production of accurate and consistent blade attributes, for all metric attributes in combination.

4.4.2 Non-metric attribute variability by TC and assemblage

Non-metric attribute groups were based on blade shape and ridge patterning on the dorsal surface. In this respect, the recording system used to quantify the attainment of each knapper with regard to replicating their target blade form was based on standard typological classifications. For shape, those classifications reflected the possible orientation of the edges, that is, were they parallel, convergent, or pointed? For ridge patterning, they reflected the number of ridges and where they occurred on the dorsal face of the piece, either single and centrally, two and laterally or other, generally meaning more than two ridges, without definable pattern. It was hypothesised that blade shape would be maintained and ridge patterning would break down, so in that respect, there would be little association or co-occurrence between blade shape and any specific type of ridge patterning. It was expected that the more skilled knappers of TC1 would all outperform their lesser skilled counterparts in TC2, in terms of replication of the non-metric or discrete attribute types.

First viewing of the overview data (Table 4.9) ran counter to the expected difference between TC1 and TC2, in the rate at which the non-metric attributes of the target form were achieved; the knappers of TC2 appeared to outperform their more skilled counterparts in TC1. Where ‘parallel edges’ was the target form, 57% of TC2 removals achieved this against 17% of TC1. For the ‘central ridge’ it was 39% and 18% for TC2 and TC1 respectively. This apparent anomaly does have to be set against the fact that even when ‘parallel edges’ and ‘central ridge’ were not the target attributes, they were still achieved in the highest proportions by knappers of both chains, a fact perhaps indicative of the design of a blade core. To put the data into perspective and align the TC results with their expected skill levels, the higher levels of skill in TC1 were probably best illustrated by the knappers’ putative ability to achieve different attribute patterns when the target form changed from the original parallel sides, central ridge combination. Although this was only between 8% - 10% of occurrences for TC1, it could be suggested that this was a better achievement than the <1% performances of TC2 (see the ‘total’ rows for each TC in Table 4.9). This likely illustrates that the higher levels of skill possessed by the members of TC1 better enabled them to adapt their knapping strategy to accommodate changes in form. It also enabled them to better overcome any possible attribute outcomes that could be attributed to the core design.

		Shape							Ridges						
TC & knapper	Total Removals	Parallel count	%	Point count	%	Cnvrgnt count	%	Total	Central count	%	2 lateral count	%	Other count	%	Total
TC1 K1	34	18	64	2	7	8	29	28	19	68	3	11	6	21	28
TC1 K2	44	21	50	3	7	18	43	42	24	57	6	14	12	29	42
TC1 K3	30	21	84	1	4	3	12	25	6	24	11	44	8	32	25
TC1 K4	51	33	69	10	21	5	10	48	20	42	9	19	19	40	48
TC1 K5	41	27	75	3	8	6	17	36	13	36	7	19	16	44	36
TC1 K6	58	47	82	5	9	5	9	57	23	40	10	18	24	42	57
TC1 Totals	258	167	71	24	10	45	19	236	105	44	46	19	85	36	236
TC2 K1	46	38	88	3	7	2	5	43	24	56	4	9	15	35	43
TC2 K2	34	31	91	0	0	3	9	34	19	56	1	3	14	41	34
TC2 K3	30	24	83	1	3	4	14	29	10	34	1	3	18	62	29
TC2 K4	19	12	67	5	28	1	6	18	11	61	1	6	6	33	18
TC2 K5	40	35	90	1	3	3	8	39	17	44	1	3	21	54	39
TC2 Totals	169	140	86	10	6	13	8	163	81	50	8	5	74	45	163
TC1 & TC2 TOTAL	427	307		34		58		399	186		54		159		399
TC1 Tgt form achieved & % of total		**39**	**17**	**18**	**8**	**18**	**8**		**43**	**18**	**19**	**8**	**24**	**10**	
TC2 Tgt form achieved & % of total		**93**	**57**	**1**	**1**	**1**	**1**		**64**	**39**	**0**	**0**	**21**	**13**	

Table 4.9. Individual shape and ridge pattern achievement by TC and knapper. Shaded areas indicate the target form attribute, in each instance.

Before Chi square testing was conducted on the rate, or probability at which attribute co-occurrence existed, it was apparent from some of the low counts of single attributes, that sample sizes would likely be too small for such analysis to be conducted on a knapper-by-knapper basis. This was because the target form changed from generation to generation (see pointed shape, lateral ridges and ‘other’ ridge patterns in Table 4.9 above). Shennan (1997:108) states that no category should have an *expected* value lower than 5, with Yates, Moore & McCabe (1999: 734) relaxing this ruling slightly, with the caveat that no more than 20% of the *expected* counts should be less than 5. In the first instance, total co-occurrences were tested by TC and not knapper, in an attempt to circumvent the ‘<5 problem’ created by small sample sizes. At this level of analysis, counts of less than 5 appear in the *expected* data for the following co-occurrences: TC1 pointed with 2 lateral ridges; TC2 pointed with central ridge, pointed with 2 lateral ridges, pointed with other ridge and convergent with 2 lateral ridges. So, performing Chi squared tests on data at the individual knapper level was not viable due to splitting the categories and therefore physical sample count per category, down to even lower levels. To overcome the problem of small (n = <5) categories, Chi squared analysis was run on the data at transmission chain level, to try and ascertain if there was any relationship between the type of ridge patterns produced and the achievement of blade shape. Table 4.10 shows the observed and expected data and the critical values obtained by using the formula highlighted in section 3.5.3, together with the resultant Chi *p*-value generated by Microsoft Excel. The objective was to determine whether skill acted as a driver for the survival and transmission of certain combinations of metric and non-metric attributes.

OBSERVED DATA

TC1 Counts	Shape			
Ridge pattern	Parallel edges	Convergent	Pointed	Total
Central Ridge	74	20	11	105
2 Lateral Ridges	39	4	3	46
Other Ridge	54	21	10	85
Total	167	45	24	236

TC2 Counts	Shape			
Ridge pattern	Parallel edges	Convergent	Pointed	Total
Central Ridge	66	9	6	81
2 Lateral Ridges	8	0	0	8
Other Ridge	66	4	4	74
Total	140	13	10	163

EXPECTED DATA

TC1 Counts	Shape		
Ridge pattern	Parallel edges	Convergent	Pointed
Central Ridge	74.301	20.021	10.678
2 Lateral Ridges	32.551	8.771	4.678
Other Ridge	60.148	16.208	8.644

TC2 Counts	Shape		
Ridge patterns	Parallel edges	Convergent	Pointed
Central Ridge	69.571	6.460	4.969
2 Lateral Ridges	6.871	0.638	0.491
Other Ridge	63.558	5.902	4.540

	Shape	
	TC1	TC2
Confidence	0.05	0.05
Degrees of Freedom	4	4
Ridge pattern		
Central ridge		
Chi²	0.011	1.396
Critical Value	9.488	9.488
Reject Null H	No	No
Chi *p*-value	0.995	0.498
Reject Null H	No	No
2 lateral ridges		
Chi²	4.475	1.314
Critical Value	9.488	9.488
Reject Null H	No	No
Chi *p*-value	0.107	0.518
Reject Null H	No	No
Other ridge		
Chi²	2.258	0.771
Critical Value	9.488	9.488
Reject Null H	No	No
Chi *p*-value	0.323	0.680
Reject Null H	No	No

Table 4.10. Observed, expected and Chi squared summary table for blade shape and ridge pattern, by transmission chain.

Against a null hypothesis that there was no significant association between blade shape and ridge pattern, in all cases the critical value was greater than the x^2 value and in all cases the x^2 *p*-value was greater than 0.05 (Table 4.10);

an outcome meaning the null hypothesis could not be overturned in favour of any alternatives. Although a relationship between shape and ridge pattern could not be proved at the group level, on an individual basis form did change and was reflected by the blades passed through each of the respective TCs. To this end, some basic examination of attribute co-occurrence was conducted by knapper, on an intra-assemblage basis.

Analysis of co-occurrence or how pairs of variables were achieved together, again, on visual inspection of the data seemed to indicate counter intuitive results. Although it could not be proved with significance testing because of small sample sizes, the knappers of TC2 appeared able to maintain the 'parallel edge with central ridge' form for three generations with the fourth generation keeping the ridge but losing the parallel edges (Appendix 2, Table 2). In TC1, the initial target form was lost immediately in the first generation of copying. The impact of this was to place the remaining knappers in the chain with different non-metric attribute combinations to replicate. Again, although it was unable to be proved with significance testing, as discussed in section 4.4.1 with reference to the metric attributes, as the ridge patterning changed and became less regular, it seemed likely that it became more difficult to knap/copy whilst also maintaining the other target form attributes; a prognosis supported by the fall in achievement rates from 43% to 24% for 2 generations and then to zero (Appendix 2, Table 1). With regard to internal consistency, despite a shift away from the base target form instigated by the preceding chain member, knapper 2 of TC1 still managed to knap 57% of all convergent points achieved with a central ridge and 42% of all pieces bearing a central ridge also possessed convergent edges (at 2/3 of length). The relative closeness of these two percentages, when compared with all other knappers of both chains (excluding knapper 1 of TC1) provides a positive measure of the consistency required to produce standardised blade forms on a serial basis.

In terms of achievement of non-metric attributes measured against the two hypotheses, blade shape was not effectively maintained (counter to expectation), but ridge patterning did break down, as expected. There was also little co-occurrence between blade shape and ridge patterning. Much of this failure can be accounted for by the fact that this was the first experiment in the series and despite relevant training and the TC1 knappers passing the required skill assessment (Chapter 3), skill levels for the entire knapping cohort were not high enough to achieve the serial reproduction of accurate blade forms. Even the performance of knapper 2 was not sufficient enough to achieve consistent replication of all target form attributes simultaneously. Despite the obvious breakdown in achievement and transmission of form, demonstrated in Appendix 2 (Tables 1 and 2), there still remained a question of effectiveness, regarding the subjective nature of typological classifications; shape and ridge patterning, in this case. Although they were allocated as discrete measures, largely because of the practicalities of classification and maintaining sample sizes, the reality of the situation is that ridge patterning and level of edge convergence both operate on a continuum. For example, when does one and half ridges become two, or when does edge convergence start (or stop) becoming a point-form? It is this type of issue that would also be on the mind of the knapper when trying to replicate their specific target form and one that would likely affect transmission of form even where knapping was conducted with very high levels of skill. So, in situations where expert levels of knapping were absent (both TC1 and TC2 in this case), attempts to replicate a form with one complete ridge and one partial ridge could easily be transmitted as one with two complete ridges, or in terms of shape, turn a parallel edged blade form into one bearing convergent edges. On this basis, when attributes cannot be objectively measured, especially in a reductive craft like knapping, subjective differences in form are open to variation in perception both at the knapping stage and also when being typologically classified.

4.4.3 Metric variability of target forms by TC

When examining the progress of metrical lithic target form via the chosen form each knapper elected to pass through the chain, there was distinct division between the outputs produced by the differing skill levels on which each TC was based. The dimensions of the base target form at the start of each TC were 40mm. long and 10mm. wide. As noted in the discussion around Tables 4.3a –

4.6b, the more skilled knappers of TC1 were better able to control for blade length, whilst the less skilled members of TC2 were unable to manage the knapping dynamic required to produce length on a serial basis (see also CVs by knapper in Table 4.1). Similarly, this behaviour was displayed by the differing ‘chosen form’ trajectories illustrated by the divergence from the common starting point of both chains, marked x in Figure 4.4. With regard to the specific transmission of form by each TC, the failure of TC2 to produce consistent blade length resulted in the more accurate transmission of blade width (Figure 4.4). To put these differences in context, it should be reemphasised that in each TC, all knappers were instructed to attempt reproduction of *all* attributes of their respective target forms, as closely as possible. The common point of reference is how few generations (3 in this case) it took for the original dimensions to change and move away from the base target form.

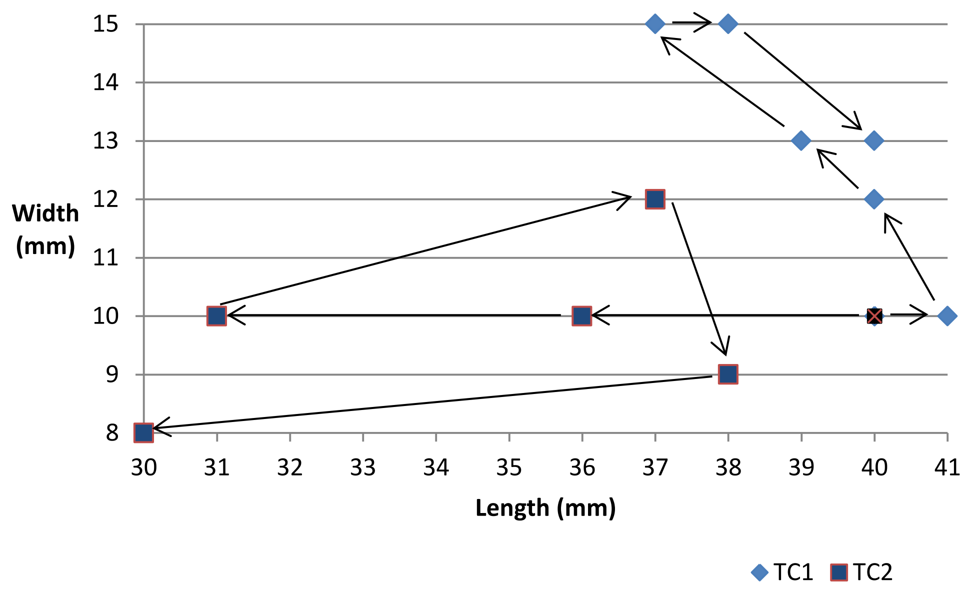


Figure 4.4. The trajectory of successive target forms showing the divergent nature of metric variables from the base target form (marked x), by TC. As the chosen form passed through each TC, the more skilled knappers of TC1 were able to control for length more effectively than the less skilled knappers of TC2.

4.4.4 Non-metric variability of target forms by TC

Accompanying metric or dimensional change is the issue of lithic form, which ultimately has an attendant impact on typological classification. Figure 4.5 illustrates that for both TCs, there are points where aspects of target form (shape and ridge pattern attributes) were achieved in combination. However, it is clear that in both instances, it took only 3 generations for both attribute types to diverge significantly enough that the subsequent generations of knappers were producing a completely different typological form. For example, in TC1 the common base target form of parallel sided blade with a single central ridge, had by generation or knapper 3 (K3) evolved into a point form with 2 lateral ridges (Figure 4.5). This change in typological definition does however have to be tempered or viewed subject to the restrictions imposed by the boundaries discussed in section 4.4.2 above. Here, it was stressed that in reality non-metric attributes are not discrete and to some extent, for both knapper and analyst, the categories are subjective and etic in nature. Imposed classification of form, which is often marginal in nature, meaning it exists between the boundaries of different typological classifications, can change the way an assemblage or results of a transmission chain are viewed. Comparison of the schematic Figure 4.5 with the photographic outlines presented in Figure 4.6, where actual attribute achievement has been highlighted, illustrates the relative inefficiency of classifying subjectively viewed attributes. For more detailed pictures of individual blade forms, see Appendix 3.

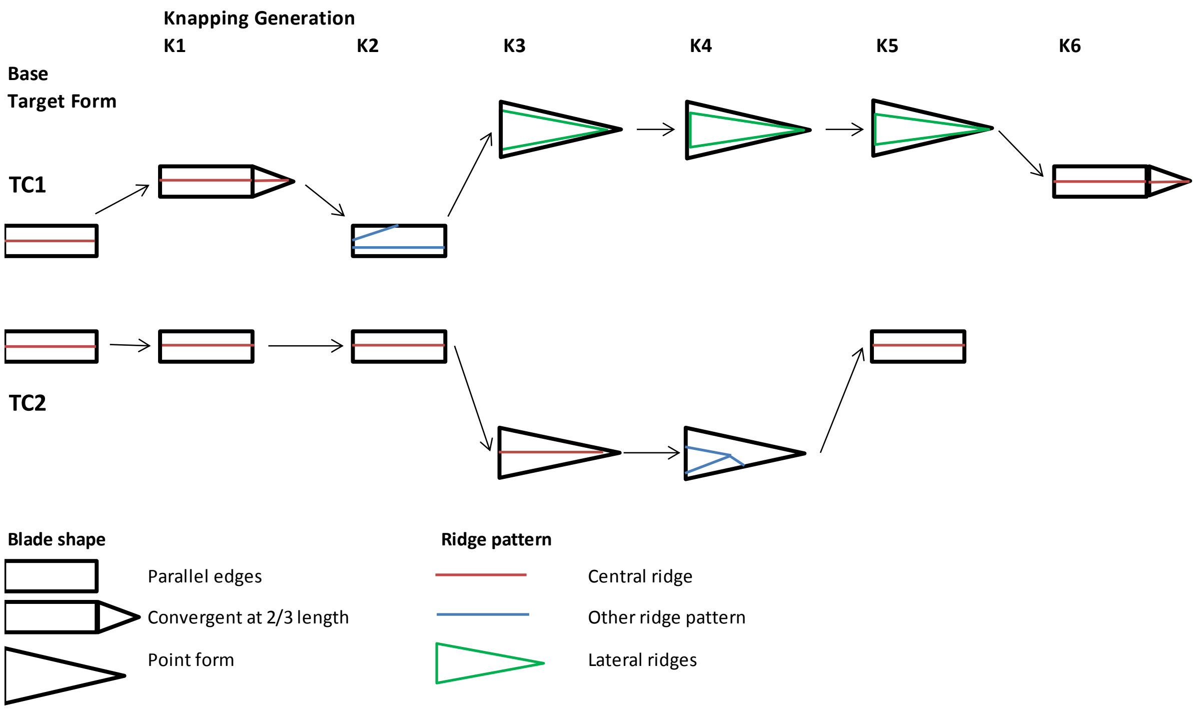


Figure 4.5. Schematic representation of the trajectory of successive target forms by TC showing divergence from the blade shape and ridge pattern of the base target form.

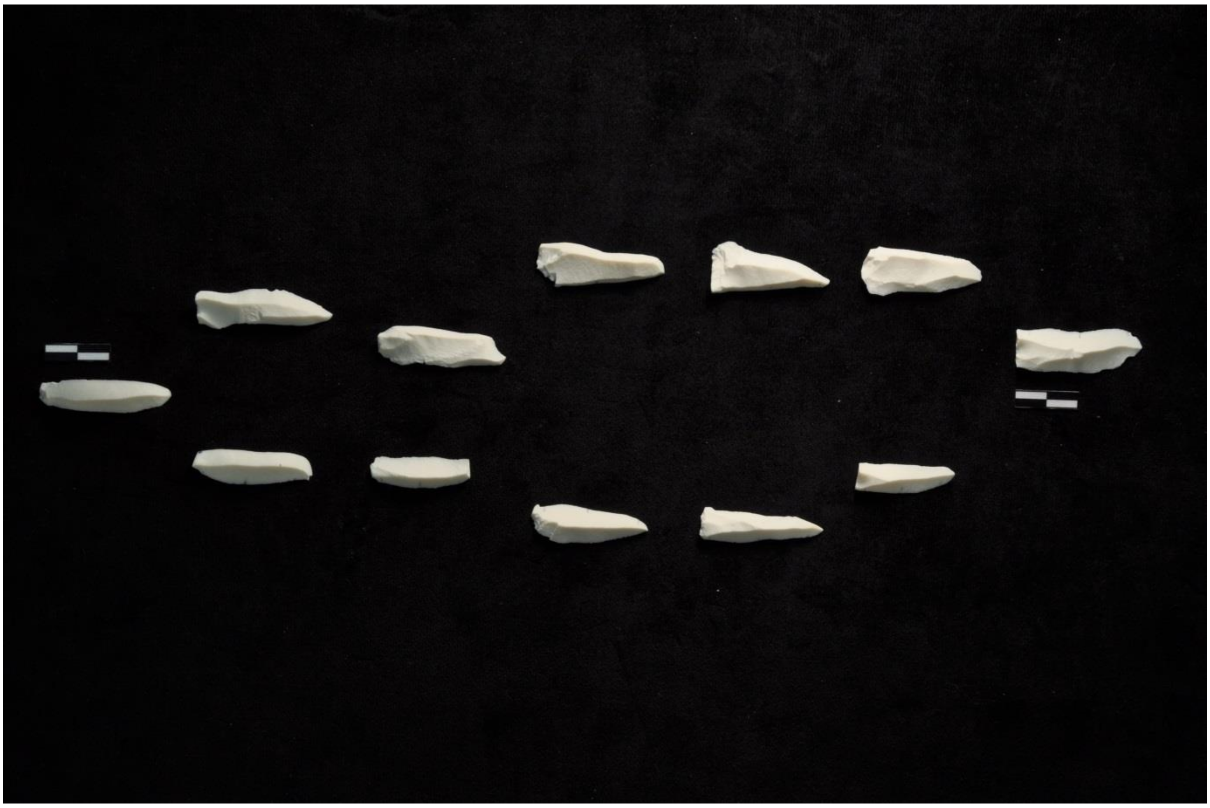


Figure 4.6. Photograph of TC1 (top row) and TC2 (bottom row) chosen forms showing the trajectory of blade shape and ridge pattern through each of the TCs. Comparison with the schematic in Figure 4.5 shows a more subtle or often partial achievement of respective target form attributes. Photograph: S. Page

As indicated by the linear regression and sub 0.05 *p* values of the metrical data (section 4.4.1 and Figure 4.2), it was likely that skill level would also have a distinct difference on the emergent blade forms as they passed through each TC. In combination, the initial 2 knapping generations of TC2 maintained blade width, parallel edges and a central dorsal ridge before they lost form and also started producing point forms. Although Figure 4.5 illustrates the appearance of a longer maintenance of base target form in TC2, it was at the expense of blade length. For the more skilled knappers of TC1, it appeared they were willing to sacrifice other attributes (both metric and non-metric) to maintain and pass on blade length; the opposite pattern to that displayed by the lesser skilled knappers of TC2. This was a skill related process and likely based on what was regarded as important or in this instance, achievable, in the blade making process, by each skill level respectively.

4.4.5 Co-occurrence: achievement of metric and non-metric attributes by transmission chain

The previous sections have shown how skill levels significantly affected the cultural transmission of metric and non-metric measures of lithic form. This section is a narrative describing the likely process which led to the TCs pictured in Figure 4.5 and 4.6 where limitations of knapping ability were working in conjunction with the typological issues discussed above. In this context, it can be suggested that skill level was acting as a driver for the survival and transmission of certain combinations of metric and non-metric attributes. For TC1, the base target form was parallel sided with a single central ridge. Knapper 1 failed to achieve that combination and transmitted a convergent form maintaining only the central ridge attribute. Knapper 2 attempted the convergent form but chose to transmit a parallel sided form with ‘other ridge pattern’ to the next knapper in the TC. In this instance, the trait that survived in terms of producing fitness of target form, was blade length, which was transmitted at the expense of both central ridge and convergent form attributes. Knapper 3 (K3) had a difficult ridge pattern to replicate, which was not copied exactly, resulting in the production of a closely related but different lateral ridges pattern. Parallel sides were also lost and replaced by a point form. Length again became the surviving trait, as only vestiges of the original form could be discerned. For the next two generations, ‘point form with two lateral ridges’ survived and was transmitted, carrying completely different attribute patterns to the original target form (Appendix 2, Table 1). For TC2, Figure 4.5 showed a longer, 3 generation survival of the original ‘parallel sided with central ridge form’. As shown in Figure 4.4, the lesser skilled knappers transmitted blade width but lacked the ability to effectively manage blade length. In this respect, to ensure the original parallel edged and central ridged attributes remained and co-occurred together, meant that blade length was the trait compromised by the knappers of TC2. At the micro-level of the culture evolutionary process, marginal variation in attribute form, such as small changes in the degree of distal taper, even when introduced by the more skilled knappers of TC1, resulted in profound cumulative changes, to the extent that after 3 or 4 generations of copying, certain trait combinations disappeared completely, such as blades with a single ridge and parallel sides. The net result of this process was the emergence of different typological forms.

4.4.6 Co-occurrence: results from comparing measures of 3D metric shape with degree of taper

Further exploration of the emergence or evolution of form was achieved by examining the relationship between three dimensional shape (Euclidean distance) and degree of blade taper, when comparing the difference between each knapper’s target form, their assemblage and the blade they elected to pass through the TC. The scatters in Figure 4.7 are three dimensional measures of each knapper’s removals, that is, a single combined measure of Euclidean distance from the target form, in terms of length, width and thickness, on the *x* axis, plotted against how each removal differed from the target form in terms of taper or shape on the *y* axis. Each dot on the chart was a removal; the red dots were the target forms, the blue dots the chosen forms. The scatters show, from the horizontal closeness of red and blue dots and denser clusters in the less than 10% area of the chart, that TC1 knappers elected to pass on closeness of overall blade dimension at the expense of taper or shape.

Conversely, when TC2 knappers chose which removal to pass on, they elected taper or shape ahead of dimension, although as learned from previous data, this was due to their inability to produce the longer form, resulting in transmission of shape only.

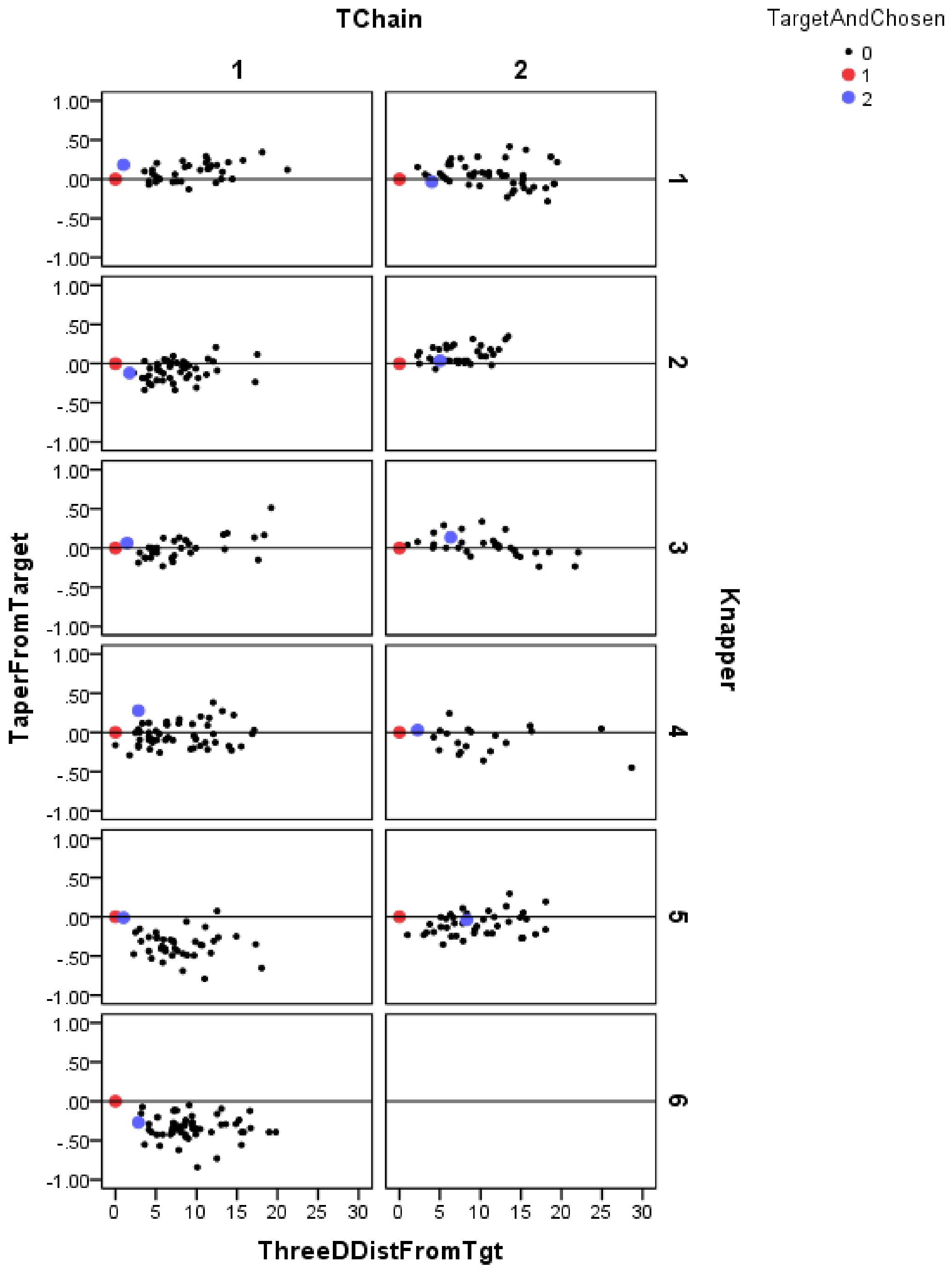


Figure 4.7. Plotting Euclidean distance from target form against difference in taper from target form. Each individual graph illustrates the assemblage of each knapper. TC1 is represented by the graphs on the left and TC2 the right. Red dots are the target form of each knapper, blue dots are the forms chosen to pass through the TC.

Figure 4.8 confirms this pattern of reproduction and selection. The *x*-axis of each column represents the change in taper or shape from the target form of each knapper. In TC2, the chosen form, contained in the blade forms represented by the red bar, is always close to the centre line and therefore also close in degree of taper or shape to that of the target form of each knapper. In TC1, it is further away from the centre, indicating other attributes, specifically length, were influencing the transmission process and surviving as traits at the expense of overall blade form.

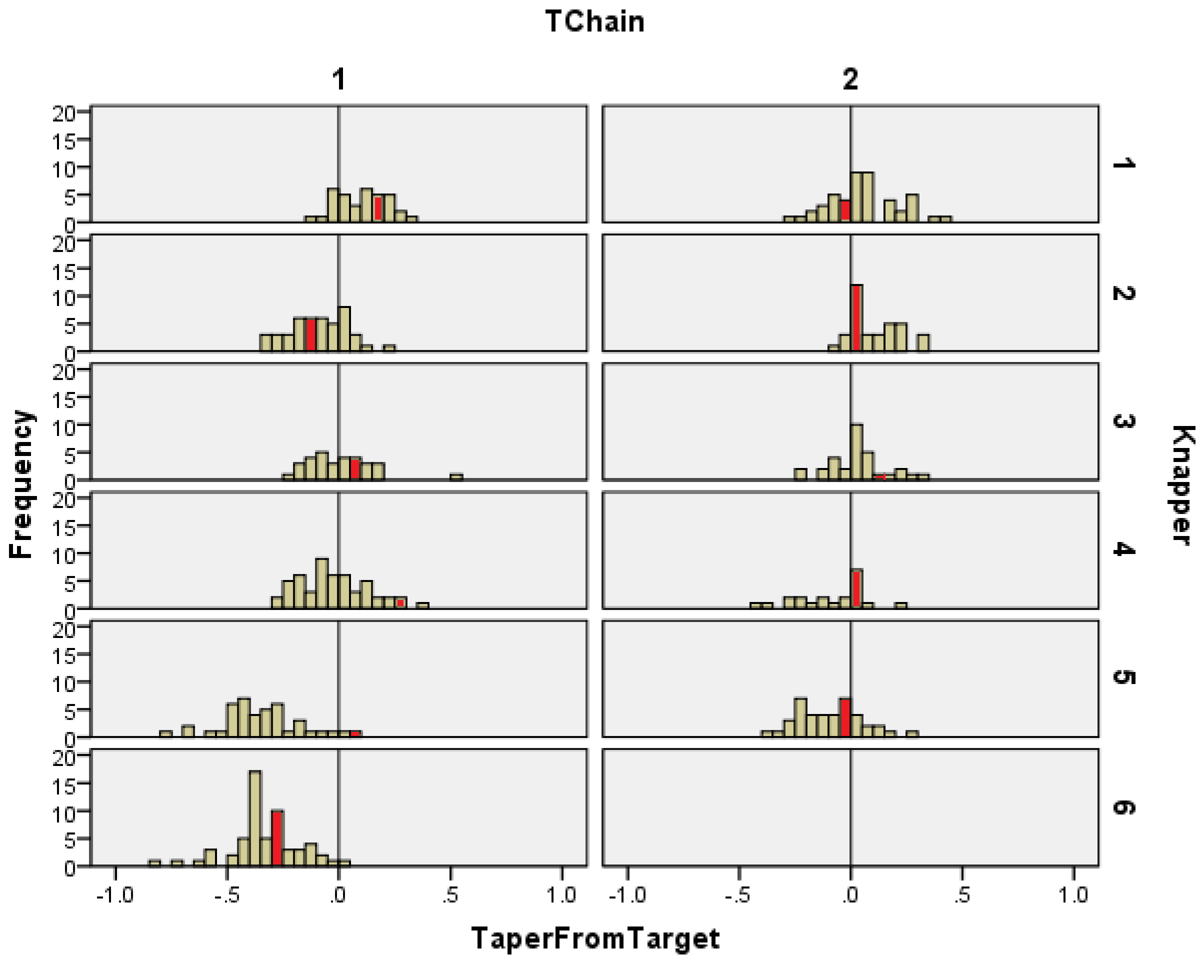


Figure 4.8. Illustrating the propensity of TC2 knappers to produce and/or pass on more blade like forms than those of TC1.

4.5 Conclusions and effectiveness of Experiment 1

The main objective and marker of skill in the context of blade production is the achievement of both metric and non-metric attributes of the target form, simultaneously and on a serial basis. The most obvious outcome of Experiment 1 was that neither chain effectively achieved this. However, this non-achievement was reached in two completely different ways, which can best be summarized by reference to the original hypotheses. They were that firstly, CV levels would be the same for each attribute (according to their TC) and secondly, the level of difference between TC1 and TC2 would reflect the higher levels of skill possessed by the TC1 knappers. If there was difference between the output of the two TCs, then the third hypothesis was the testing of whether skill acted as a driver for the survival and transmission of certain combinations of metric and non-metric attributes.

The assemblages of the more skilled TC1 indicated that length was achieved more consistently (Table 4.2 & Table 4.3a – 4.4b), likely at the expense of the non-metric attributes, such as ridge patterns and blade shape. This was classically illustrated by knapper 2 of TC1 who, despite co-achieving both non-metric attributes 24% of the time, decided to pass on a blade form not bearing that attribute pattern, but one that was metrically closer to the target form, instead. In contrast, the less skilled TC2 group, whose achievement of metric attributes, especially length and thickness was generally less consistent than in TC1 (length CV 20.2 versus 17.5 and thickness CV 57.6 versus 51.9, for TC2 and TC1 respectively (Table 4.1)), managed to maintain the pattern of non-metric target forms for three out of five generations, before the chain broke down completely (Figure 4.6). The strength of the pattern of metric attribute achievement for the more skilled knappers was also supported by the positive R^2 and resultant *p*-values achieved by TC1 (Figure 4.2) compared with the lack of significance in TC2 (Figure 4.3). In each case, the target form chosen by each knapper to pass on to the next generation of the TC was agreed by the experiment organisers, so in this respect, each subsequent generation was definitely receiving the closest match to the target form they received. However, overall form was not consistent in each TC and counter to expectation, individual attribute CVs each behaved differently. In addition and in line with expectation, the attributes that changed or varied most were different in each TC; this variation was seemingly created by the different levels of skill possessed by the members of each chain. In attempting to explain the large range of metric and non-metric variation as the target forms passed through both chains, in addition to the conclusion that that the levels of skill required to fulfil the criteria of successful blade making were not met in either TC1 or TC2, it can also be seen that the differing levels of skill also affected the transmission and evolution of blade form in different ways. When looking at individual assemblage data, it was apparent that only knappers of TC1 displayed the kind of skill levels required to produce repeated achievement of target form attributes, notably blade length. The more difficult phenomenon to explain was why target form in TC1 evolved with more consistent reproduction of metric attributes, while conversely, in TC2, ridge patterning and blade shape should be easier to match, especially as the chosen target form passed through the early generations of the transmission chain.

In both TC1 and TC2, levels of change in metric and non-metric traits were markedly in excess of the 3% advocated by Eerkens (2000) and stated in the objectives section (4.2), as levels that would be indicative of stylistic drift caused by human perceptual limitations. In this sense, change has not been random and therefore, other culture evolutionary factors have driven the shifts in form displayed by all knappers. As discussed above, differential skill levels would appear to be an integral factor in the cumulative evolution of form, affecting both continuous and discrete variables alike. Changes in metric variables, by their continuous nature, contribute to accretional change in the output of each knapper. The variation produced by this process is then fed into the lithic transmission chain to become part of the evolutionary process. Although non-metric traits such as parallel edges or central ridge are defined as discrete, in a present or absent way, the reality of stone knapping is far more marginal and blends of different ‘discrete’ traits start to appear (see Figure 4.6). For example, the central ridge achieved by K1 of TC1 was accompanied by a smaller unrelated and seemingly inconsequential dorsal scar. In trying to reproduce this scar pattern, K2 lost the central ridge but did achieve an off-centre ridge that ran from butt to tip, the convergent form was also lost and as mentioned in Section 4.4.1 and 4.4.5, K2's strongest target trait: length, survived, carrying with it a merging of the original scar pattern and edge shape. The effect of this merging of discrete factors accumulated further in the following iteration, resulting in total loss of the original trait patterns after 3 generations, with length remaining the only consistently surviving attribute. The overriding factor in this process was skill; in a knapping context, form was evolving because of trait blending caused by each knapper's inability to control for multiple attributes simultaneously. In this sense, lack of skill is creating culture evolutionary errors, which cause lithic form to mutate and change over multiple generations of copying.

Chapter 5.

Accounting for and quantifying Acheulean variation

5.1 Introduction

Chapter 4 demonstrated the role skill differential can play in the evolution of artefact form. It also demonstrated the creation of variation in a lithic assemblage, centred on a specific target form, in a TC experiment with tightly defined knapping objectives. By extension, the purpose of this chapter is to highlight and explain existing thought on a long standing lithic based archaeological issue; that of accounting for stasis or low levels of variation in Acheulean handaxe form. The objectives of the three handaxe based experiments that follow this chapter are also conducted within structured TCPs, to help provide a new and broader understanding of the factors that may have impacted on Lower Palaeolithic technology, to create the constrained tool form seen in the archaeological record. In addition to the issues already discussed in Chapter 2 (specifically sections 2.1.2 – 2.1.6), understanding of Acheulean variation is traditionally framed by the following three distinct archaeological paradigms, each of which will be discussed in turn.

- Raw material
- Reduction and resharpening
- Demographic theory

In its most basic form, the Acheulean emerged in Africa with the ability to strike large flake cores from outcropping nodules or tabular veins of stone. With reference to Harris & Isaac (1976), Ludwig & Harris (1998: 98) stated this first occurred circa 1.7 Myr ago, at sites along the Karari escarpment of Koobi Fora, Kenya, with the emergence of large, standardised, single platform cores referred to as Karari scrapers. More recently, crude unifacially or bifacially shaped handaxes also produced from large cobbles or tabular clasts of phonolite have been reported from Kokiselei 4, a site in West Turkana, Kenya and confirmed as dating to 1.76 Myr ago (Lepre *et al,* 2011). Despite contention regarding dating between sites, as a region, East Africa appears to bear witness to the initial development and transmission of this new cultural phenomenon with other examples of early Acheulean large flake based tools dating between 1.76 – 1.4 Ma, also from Olduvai Gorge (Leakey, 1971), Konso (Asfaw *et al,* 1992; Beyene *et al,* 2013) and Gona (Quade *et al,* 2004). As a technological group, these Earlier Pleistocene examples tended to be unifacially exploited and minimally trimmed handaxes that Isaac (1977: 486) initially referred to as knives. The highly symmetrical and bifacially worked handaxes used as the target forms for the transmission chains in Experiments 2 – 4 in this thesis, are more reflective of handaxes with higher degrees of refinement, which had evolved by the Middle Pleistocene. Examples could be derived from early Middle Pleistocene African sites such as Olorgesailie (Isaac, 1977) where lava was the raw material but it was deemed that handaxes knapped from flint, such as those from middle Middle Pleistocene European sites and authored by *Homo heidelbergensis*, the colonising species of the time (Rightmire, 1998), would represent more appropriate examples for the experiments. This decision was made because of the wider range of knapping skills required to reproduce such a form, as part of the process that involved the shaping and thinning of a large flake core, which the porcelain blanks created for these experiments were designed to provide standardised examples of. Flint is also the raw material that the porcelain preform cores most closely resembled in terms of chonchoidal flaking properties and general knapping characteristics (see Chapter 3). As well as presenting a more specialised knapping task, Acheulean handaxes from this period have also been considered as vehicles for the communication of personal identity (Field, 2005) and ecological and social information through handaxe discard patterns (Pope & Roberts, 2005); concepts not so readily attached to the less sophisticated handaxes from the earliest Acheulean. In this respect, handaxes from the middle and later Middle Pleistocene have already been considered as artefacts that communicate information between different generations of knappers and as such, this positions them well in the context of cultural transmission of physical artefact form.

5.2 Accounting for existing ideas on Acheulean variation

Cumulative cultural evolution implies more than a direct analogy with Darwin's biological description of 'descent with modification' (Darwin, 1859). In cultural terms, change may be the result of random drift and occur over single or multiple generations. However, there are also elements of cultural descent that are less stochastic and are deliberately maintained and built upon through multiple generations of reproduction or copying (Richerson & Boyd, 2005). This is effectively a 'ratcheting' process (Henrich & McElreath, 2003; Tomasello *et al,* 1993; Tomasello, 1994) that allows change or cultural variation to be inherited, developed, controlled and continually transmitted (vertically and horizontally), as opposed to a process where cultural variation or novel procedure develops for short periods of time, before going extinct, due to failure in the transmission process. In terms of lithic tradition, quantifying degrees of change or variation is open to many influencing factors (see Chapter 2). In order to bring objectivity to the process of defining change and its temporal pace, much of how we view variation in lithic culture is quantified by metrical data. In the context of the Acheulean and specifically the handaxe, one of the foremost metrically based typological studies of the latter half of the 20th century was that of Roe (1968), which the methodology and use of in this thesis, was discussed in Chapter 3.

Despite the status subsequently achieved by Roe, he formulated his ideas during the time period described by Sackett (2014: 4) as the 'Bordesian era' and it could be said that the foundations of Roe (1968) lie in the typological system established by Bordes (1961b). Bordes' system also relied on a set of handaxe metrics for length, width and thickness, which were used to generate dimensional ratios as the basis for defining the following handaxe shapes: triangular, subtriangular, cordiform and ovate. Those basic shapes were then subdivided into a total of twelve handaxe types defined according to the relative bivariate position of the different ratio or dimensional measures, (Figure 5.1).

The use of Bordes' (1961b) system has undoubtedly defined how handaxe shape is referred to on an international basis, again see Debénath and Dibble (1994) as evidence of its widespread acceptance. However, at a time when the quest for objectivity was a major tenet of processual archaeology, especially in the Anglo-American world, the approach of Bordes (1961a; 1961b) undoubtedly motivated other scholars, of which Roe may, or may not have been one. Although based on British handaxes from the Lower and Middle Palaeolithic, Roe's (1968) study, like that of Bordes (1961b) before him, also influenced the interpretation of many subsequent Acheulean assemblages in Africa and Eurasia (Clark, 2001; Gowlett, 2005; Leakey, 1994; McNabb *et al,* 2004; Roe, 2001; Wenban-Smith, 2004; Wymer, 1968). Despite refinements to the original dimensions and attributes measured (Isaac, 1977; Lycett *et al*, 2006; Lycett & Gowlett, 2008; Wynn & Tierson, 1990), Roe's methodology still remains a mainstay of classifying metrical Acheulean variation.

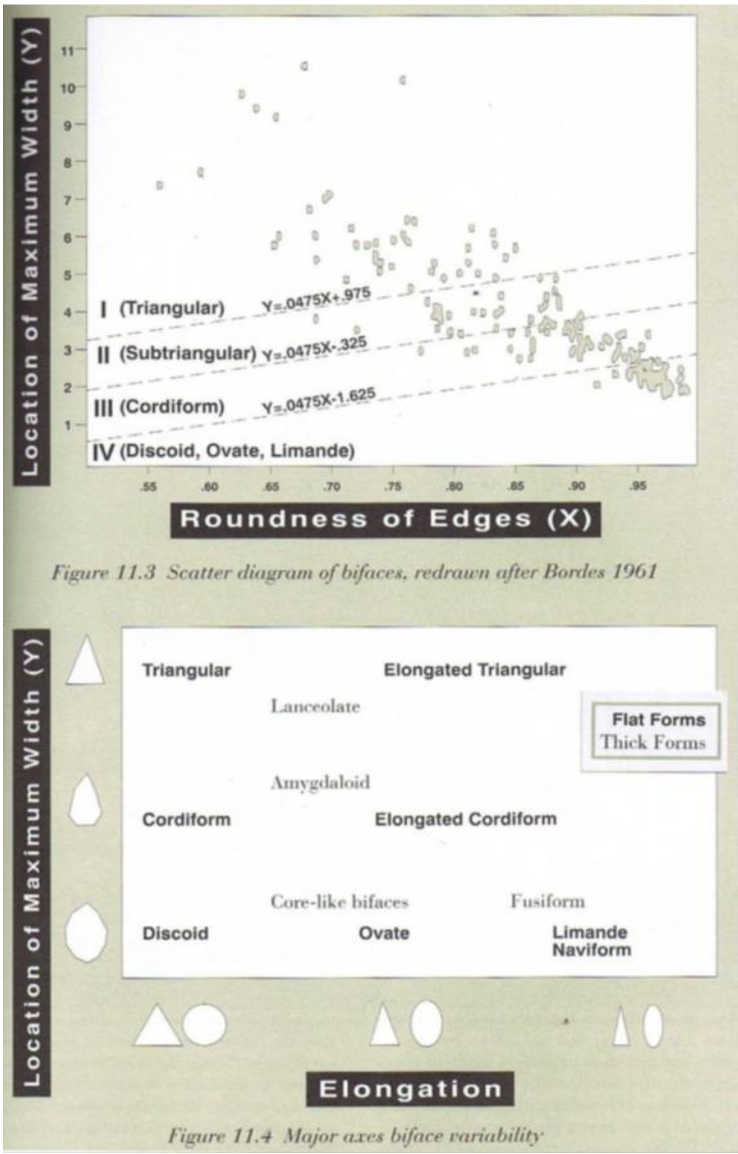


Figure 5.1. Shape classification of the main and subdivided handaxe types, according to Bordes (Debénath & Dibble, 1994: Figure 11.4).

The original aim of the Roe typology was to objectively classify Acheulean assemblages as being dominated by a specific type or shape of handaxe - either point, ovate or cleaver. From those classifications, in conjunction with spatial and chronostratigraphic information, Roe's objective was to propose cultural and evolutionary patterns for handaxe data, gathered from 38 sites in Britain. The distinction between the handaxe types was based on the $\frac{L1}{L}$ ratio, which is the measure of length from the widest point of the handaxe to its butt, relative to its width at other defined points on the length axis (Roe, 1968: 23-24). This ratio was fundamental for Roe in defining whether a handaxe and therefore an assemblage was defined as point, ovate or cleaver in nature. The basis for that allocation was arbitrarily decided by Roe (1968) according to the $\frac{L1}{L}$ ratio value and its >60% presence in each handaxe assemblage as follows:

Ratio Value & Handaxe Type	**Frequency & Assemblage allocation**
0.00 - 0.350 Point	> 60% = Point
	50-60% = Marginal point allocation
0.351 - 0.550 Ovate	> 60% = Ovate
	50-60% = Marginal ovate allocation
0.551 - 1.00 Cleaver	> 60% = Cleaver
	50-60% = Marginal cleaver allocation

With few assemblages classified as cleaver dominated, the effect of this typology has been to reduce handaxe variability to a pointed**:**ovate dichotomy at the individual and assemblage level. Although Roe's methodology is effective in capturing metrical variation, it seems its application has more relevance at the micro-evolutionary level, than it does for the creation of the macro-scale cultural narratives that Roe himself envisaged. Placing the two opposing and arbitrarily defined handaxe forms in a culture-evolutionary framework, which, as Roe (1981: 270) himself acknowledged, required better chronological controls for charting both the British Pleistocene sequence in isolation, and for making the inevitable comparison to the European record, has created friction amongst scholars attempting to apply differing theories that account for Acheulean variation. Roe's system may have measured and captured this variation efficiently but as McPherron (2006: 267) has subsequently pointed out, it does little to effectively explain the causes of that variation.

Much of the groundwork in providing a new framework for addressing the causes of Acheulean variation was laid by Bradley & Sampson (1986) who used a programme of experimental knapping to replicate archaeological assemblages, using raw material that was local to the sites in question. Their aim was to explore the processes that likely influenced the actions of Palaeolithic knappers, at the micro-level of individual handaxe (and attendant debitage) production. Bradley and Sampson (1986) presented findings that fell into two main camps: firstly that raw material influences tool design and therefore variability more than the knapper (p35). However, and secondly, it also acknowledged that final tool form was also governed by "traditional tool design habits" (p30) and the knappers own ability to match his/her intention, based on possessing the relevant level of skill or ability required to execute that intention, on a strike by strike basis, throughout the whole reduction sequence. From these conclusions, and the dissatisfaction with the shortcomings of Roe's (1968) culture historical approach, it is possible to see the establishment of two main archaeological schools of thought in accounting for Acheulean variation: firstly that of raw material and secondly, tool reduction sequence. The raw material theory, although influenced by others, notably Bradley & Sampson (1986) and Jones (1979), has in the United Kingdom, become associated primarily with the work of Ashton & McNabb (1994) and White (1998). In a similar vein, with prior influence from Dibble (1984), the reduction theory on Acheulean handaxe variability has become associated with McPherron (1995). The proceeding sections expand on both the raw material and reduction theories with, in the first instance, specific reference to the archaeological record of the United Kingdom, followed by a wider discussion of demographic factors. By using transmission chain theory, it is possible to highlight how handaxe shape was likely mediated by differing demographic factors, each responsible for producing differing levels of transmission fidelity. As an adjunct to raw material and reduction, the way in which handaxe form was copied between generations of hominin knappers, was likely affected by the attendant systems of transmission and cultural bias most likely in each demographic scenario.

5.3 Variation and raw material

Ashton and McNabb (1994) highlighted the heavily interstratified nature of different Acheulean handaxe forms as evidence against the cultural affinity and evolutionary chronology proposed by Roe (1968). They went on to state the majority of variation in biface/handaxe form was created by available raw material and function. In this context, function was situated in the hominin creation of a tool form that follows a 'broad mental construct', as opposed to the specific 'mental template' advocated by Clark (1994: 454). The point, cutting or functional edge of the tool was produced in accordance with the broad mental construct of the required tool form but followed the path of least resistance presented by the shape and constraints of the original raw material. Ashton and McNabb (1994) supported their theory by deconstructing perceptions of the 'classic biface forms' e.g. the ovate and point that have come to be recognised and which are a direct result of typological classifications such as Roe's. They presented examples of non-classic forms from Swanscombe, as examples of types that commonly exist in many assemblages. Such forms have bifacial tips and edges but do not fit in to the classic ovate or pointed classifications, that is; they possess the functional attributes (point and sharp edges) but not the accepted form. Ashton and McNabb (1994) see the existence of a biface continuum where such forms exist in conjunction with the classic forms as evidence supporting the idea that bifaces were knapped by hominins according to a mental construct, as opposed to a tighter, more rigid mental or typological template. Difference in raw material quality was presented as the primary causal factor behind the continuum and the presence of Acheulean variation.

To explore the continuum theory as a product of raw material selection, Ashton & McNabb (1994) selected a series of bifacial industries from sites where they thought it was possible to reconstruct the original core shapes based on cortex presence and refit analysis. Their spectrum was illustrated by 'points' where at least 50% of bifaces were made on nodules which were long, thick and narrow (p185). Here emphasis on producing sharp edges would, because of the shape of the raw material, produce a longer, more pointed form. At the other end of the spectrum, only 10-20% of bifaces could be provenanced to raw material that was originally a large flake, a wide and thin nodule or a tabular flint (p187), which tended to be used for ovate or cordiform bifaces. On this basis, Ashton & McNabb (1994) concluded that following a knapping strategy based on the 'path of least resistance', the final tool form would be dictated by the by the shape of the raw material. Where there was no restriction on raw material (and for this scenario they presented the large globular nodules from which the Boxgrove assemblages were knapped), ovate handaxes were the preferred form. Between these two extremes rest a whole continuum of variation into which the non-standard forms from sites such as Swanscombe would also fit. The continuum theory rests on dismissing the arbitrary point/ovate divide of Roe, which forced Acheulean sites into either the ovate or pointed tradition and subsumed the significant levels of variation that existed at the intra-assemblage level. Ashton &McNabb (1994: 189) attributed such variation to raw material and its curation according to the requirements of function. This is undoubtedly relevant and raw material can never be underestimated as a factor that constrains or creates variation in lithic form, especially when as is the case for Ashton & McNabb (1994: 189), the initial raw material and resultant tool form is further curated as a direct result of the functional requirements of butchery and carcass processing. However, Ashton & McNabb (1994) failed to consider that variation could also be caused by differing levels of skill, failures in copying ability, type of teaching or skill transmission and stylistic drift. Each of these factors would surely produce functional attributes that existed and were maintained at the expense of producing ideal or standardised bifacial forms. By regulating issues of heterogeneous raw material, transmission chain experiments are ideally placed to explore these more socio-cultural issues.

5.4 Variation and reduction

McPherron (1995), like Ashton and McNabb (1994) and White (1998), was critical of Roe's original 1968 classification because of its typological nature and its tendency to subsume variation by forcing biface assemblages into one or other of the pointed or ovate categories, based on an arbitrary 60% presence; with the added assumption that each reflected the preferred form of the knapper. The mainstay of the McPherron (1995) reduction model was that variation in biface shape reflected differences in the goals of biface reduction or sharpening strategies. He stated (p55) that if shape was important, then reduction would happen in a way that preserved overall form but if a resharpening strategy was more important, then different areas of the biface, in this case, the tip length, will be resharpened at a differential rate to the rest of the handaxe, thereby altering the overall form of the piece. Such alteration of form would become even more pronounced after several generations of resharpening, thereby creating a continuum of variation, as opposed to discrete typological forms.

McPherron did allow for the initial size of available raw material when considering the number of resharpening iterations that could likely occur and the effect that would have on the relationship between point size, relative to the rest of the biface. However, despite this caveat, he continued to stress that the main driver of the reduction theory was achieving and maintaining a bifacial edge and not a specific artefact shape. McPherron (1995) also stated that not enough attention was paid to edge shape, which on an intra-assemblage basis also tended to display continuous variability that would run between both ovate and pointed handaxes; therefore as variation was present along a continuum, it lessened the case for the existence of ovate and pointed forms as distinct biface types at the intra-assemblage level. In terms of planform shape, he again stated that Roe's division only worked because he allocated sites as ovate or point dominated based on 60% presence but when examined at the assemblage level, the types were not distinct. On this basis, McPherron believed his reduction theory, specifically related to point or tip re-sharpening, was able to explain biface variability not accounted for by culture evolutionary or raw material theories alone.

To substantiate his hypothesis, McPherron (1995) firstly stated that when the variability present for the average value of the maximum width location was examined at one standard deviation for each site, there was significant overlap and no real examples of extreme ovate or pointedness really existed with the possible exception of a single site: Swanscombe Middle Gravels. Secondly, he used Roe's original data to look for the patterns of reduction that would fit the theory of ovates having, on average, shorter tips relative to length, greater average broadness and more refinement (thickness/breadth ratio) than bifaces from the pointed tradition. McPherron reorganised the assemblage so it was based on median tip size and not the Ovate & Elongated categories of Roe. On this basis, the entire assemblage evenly distributed itself along the tip-length axis, which McPherron interpreted as evidence supporting the high correlation between shape and tip length. Intensity of reduction is forwarded as the main factor in explaining this relationship and differences in biface shape are explained as different points on a continuum of variation i.e. ovates are more heavily reduced handaxe forms than points, with the possibility that the former is a product of iterative resharpening of the latter.

In attempting to account for variation in artefact form, McPherron considered his focus on tip reduction to be more behavioural in nature than more ecologically constrained theories relying purely on raw material quality or an overall shape based reduction strategy, which says all areas of the biface would be reduced to the same extent (p56). However, focus on point size relative to the whole biface makes the assumption that bifacial assemblages of differing shapes and sizes were primarily the products of reduction that occurred in a predictable stepwise manner or, that in the first instance, they stemmed directly from a larger or different form that existed before previous iterations or bouts of re-sharpening occurred. It is likely that neither of these scenarios offer a complete explanation, as was discovered by Iovita & McPherron (2011), when comparing Acheulean handaxes with handaxes knapped from Levallois flake blanks (during the Mousterian), and that variation in form could also be the product of poor copying ability in the form of stylistic drift or differences in skill level.

5.5 Demographic theories accounting for Acheulean variation: how they work with transmission theory and cultural evolution

Exploring demographic factors such as population density and the ability of larger group sizes to maintain higher degrees of cultural complexity (Derex *et al,* 2013), shifts the explanation of Acheulean variation away from behavioural factors of reduction strategy, or a narrow imposition of ecological factors such as raw material homogeneity, to a more expansive application of ecologically driven factors and their effect on the process of cumulative cultural evolution. Isaac (1972: 399-402) was one of the first scholars to formalise the possibility of demographic factors acting as a driver of material culture. He proposed that Middle and Lower Pleistocene hominins would have been subject to low population density, resulting in small mobile groups where interaction frequencies with other groups was restricted; meaning a low usage of and minimum difference in manufactured artefacts as cultural identifiers. In his 1977 monograph, Isaac developed this theory, proposing that culturally generated variation in the Olorgesailie basin did exist but was the product of "micro-differences between groups, coupled with a broader conservative uniformity" (Isaac, 1977: 96). If this were the case, procedure and/or rule sets likely passed from those with knapping experience, to the novice stoneworkers in a very restricted and conventional manner. In this scenario, regional micro-variation was likely created by idiosyncratic group differences in technical process, but such small differences were unable to translate into technical advances that ratcheted and operated on a cumulative basis. Likely causes for such a spatially and temporally widespread tool form failing to demonstrate a more technically progressive or identifiable role as a cultural marker, have been linked to low levels of selective pressure (Foley, 1991); likely a result of the low density populations and limited levels of inter-group contact originally advocated by Isaac (1977).

The linkage between fluctuating or low density population and Acheulean variation is perhaps best made by Lycett & von Cramon-Taubadel (2008) who attempt to explain the presence of non-handaxe bearing Acheulean assemblages for example, the Clactonian in Britain (Mithen, 1994; White, 2000) and the flake and chopper industries found east of the 'Movius Line' (Movius, 1944), by combining population or demographic dispersal models with cultural transmission theory. Due to bottlenecking along hominin dispersal routes (out of Africa, in this case), they used an 'iterative founder effect model' to demonstrate that in parallel with genetic variation, bottlenecking along dispersal routes led to a reduction in population size and accompanying genetic variation, and thus a decrease in the rate of effective socially transmitted cultural variation in lithic form. Both the Clactonian and the East Asian assemblages were at the geographic extremes of a handaxe industry whose centre of origin was Africa and on this basis, as population size decreased at the peripheries of the dispersal route, it reached levels where socially transmitted cultural variation was unable to ratchet and innovation such as the handaxe was lost to a basic and more homogenous Mode 1 technology.

The key refinements made by Lycett & von Cramon-Taubadel (2008) to the iterative founder effect model, practically making it a null hypothesis, were that levels of metric variation between Acheulean assemblages, taken from differing start points to those of the original East African sites, did not produce significant or comparable results. They also stated (p557) that whilst the model provides a foundation for explaining disparity in form, it cannot explain at least 50% of intra-assemblage variation, meaning within group variance was less likely to be a random phenomenon (i.e. drift, linked purely to geographic distance). Raw material was also discounted as a significant factor, as assemblages made from different rock types did not demonstrate average within group variations that were significantly different. The idea of low selective pressure, based on conformist bias as a mode of cultural transmission, was mooted as a frequency dependent method of transmission that could successfully work against population density/iterative founder effect acting as the sole driver of Achuelean variation. A key conclusion that can be made from these findings is that neither overall population size nor raw material work as adequate explanations for variation or stasis in lithic form. It is more likely the mode of transmission or transmission bias, as a variable independent of population size, that is acting as the key driver of variation.

Building on ideas mooted by Shennan (2001) and Henrich (2004), placing cultural innovation and transmission in a demographic framework of varying densities and levels of interconnectedness amongst hominin groups, there is scope to explore the effects of different facets or biases prevalent in socially based learning. Although representing the onset of modern human behaviour over the last 100,000 years, Shennan (2001) and subsequently Powell *et al* (2009) created models demonstrating that in combination, fluctuations in population size, density and structure could explain different patterns of cultural transmission and therefore speed, uptake and change of lithic technologies. The advance made by Powell *et al* (2009) was the ability to model populations and the impact of direct bias or learning from the most skilled individual within a group to a far higher degree of sensitivity than had been possible in previous models. This provided the ability to create comparative subpopulations, varying in their degrees of vertical or oblique learning, likely fidelity of transmission and level of migratory activity based on random walk estimates derived from ethnographic sources. From this analysis, Powell *et al* (2009) were able to demonstrate that levels of skill accumulation or cumulative cultural evolution, in addition to benefitting from larger populations, were also benefitted by higher levels of migration and contact between subpopulations. They went on to explain that this is caused by the effect increased contact has on increasing the levels of within-group variation. Higher levels of within-group variation are shown to stimulate the effects of direct bias to the extent that innovation or variation will occur at a rate which offsets any attendant levels of low-fidelity transmission or copying error. In this context, the type of bias appears critical to the degree of cumulative cultural evolution that occurs.

In an experimental context, transmission chain experiments could offer the model of Powell *et al* (2009) or Lycett & von Cramon-Taubadel (2008), a base of data formed from inter and intra-generational lithic copying and transmission. In the same way that Powel *et al* (2009) used ethnographic data to inform their random walk variables, experimental TCPs could be used to generate likely differences in variation produced by multiple generations of lithic copying, subjected to different forms of bias and types of transmission, thus providing a set of experimentally produced probabilities for the modelling of different cumulative cultural evolution scenarios. Evidence of culturally produced variation tends to be smothered and confused by the extensive depth of time and spatial range occupied by Acheulean industries. In many respects, this phenomenon has resulted in increased focus on the search for evidence of cultural transmission at the intra-assemblage level. This again relates back to the idea of micro-variation, proposed by Isaac in the early 1970's. In this context, the objective is to use experimental TCPs to model different forms of transmission, in an attempt to replicate seemingly complicated levels of micro-variation (or lack of) in Acheulean assemblages, in an attempt to explain that variation.

With small isolated groups a likely option in the production of Acheulean assemblages, Shennan & Steele (1999: 376) proposed vertical transmission with learning, or the transfer of skill, happening in a strictly parent to offspring scenario. Using the model shown in Figure 2.9, vertical transmission does account for the slow rates of cultural evolution experienced in the Lower Palaeolithic, and due to the likelihood of many different families of techno-stylistic approach, it could create high degrees of variation between individuals and groups but within a constrained or standardised form – a key Acheulean issue on an inter and intra-assemblage basis. Horizontal and one-to-many modes of transmission putatively account for high levels of variation and cultural evolution (Figure 2.9) by operation of the same processes, so may not represent suitable modes of transmission. Mithen (1999: 389-399) proposed a system of observational learning or copying, carried out with bouts of individual trial and error, which, in the nomenclature of transmission theory is, 'guided variation'. In a *sensu-stricto* context, this would result in the acquisition of a cultural trait, which then becomes modified by individual trial and error resulting in high degrees of artefact variance. For Mithen's (1999) theory to function in agreement with much of the Acheulean archaeological record, the mechanism of trial and error remains but conservative form would, according to theory, also have to be maintained, perhaps by a system involving a many-to-one transmission protocol (Figure 2.9), where techno-typological procedure was regulated in accordance with the accepted group behaviour of the many. McNabb *et al* (2004) offer a caveat to this theory by stating that even without consciously or deliberately enforced social learning, the effects of the group would have 'habituated' new knappers to produce the form and techniques they had seen around them from birth. However, whichever mechanism is correct, and levels of variation and cultural evolution are slow, as is the established view of Lower Palaeolithic industries, then any variation that remained within each group or region could have been due to factors associated with differential skill levels and stylistic drift; a scenario illustrated by the levels of variation present between the two assemblages of Experiment 1 (Chapter 4).

5.6 Stasis and random variation: is the Acheulean a genuine cultural tradition?

The idea that variation was created either by drift, idiosyncrasy, differential skill level or raw material, has raised the question of whether such differences can be regarded as cultural and as a result, whether the Acheulean should be regarded as a tradition at all. Mithen (1999) followed the line that culture has to be cumulative, a concept not easily demonstrated till the later Middle Pleistocene. To demonstrate the lack of ratcheting or cumulative cultural change, Mithen (1999: 395) shows a stasis in handaxe form in S. E. England, illustrated by the reappearing of chronostratigraphically unlinked but very similar typological forms present in a period spanning over 200,000 years. The crux of the issue rests in our ability to separate the discreet packages which, in the contemporary sense of culture, tend to exist and be viewed as interdependent parts of a fluid and fast moving whole. In this context, stasis does not preclude cultural transmission and the sharing of ideas which, although unchanging, may hold over wide geographic areas and display variation only at a broad regional level. Wynn (1995: 19) provides 'effortless reflexivity' as a non-verbal mechanism for the transmission of such techno-stylistic traditions. This allows the transmission of ideas, in this case handaxe form, between one individual and another, or perhaps more relevantly between many individuals and one (as above) and is based on what the hominin group came to understand as an appropriate or acceptable representation of a handaxe. Effortless reflexivity could exist in an observational, trial and error learning environment where the group norm (possibly subject to drift) comes to bear through gesture and non or limited use of spoken language. By definition and compared to a fully symbolic language, this is a restrictive mode of transmission, which, in combination with small, sparsely distributed populations, could help explain limited variation but allow for the long-term existence of differing regional traditions.

Lycett & Gowlett (2008) presented this idea by examining 255 handaxes from 10 different localities across Europe, Africa and India. From the measurement of 60 metric variables per handaxe, the dataset was subjected to discriminant function analysis; a multivariate technique that assesses a predefined classification (regional affinity in this case) according to independent attributes or characteristics derived from the data (the 60 metric variables), to evaluate how well the original regional classification performed (Shennan, 1997: 350-351). Results showed that in 72.8% of cases, the groups were correctly assigned to their original locations and Lycett & Gowlett (2008: 300-301) were also able to discount raw material as a main contributory factor, due to the different types and combinations of material present in each assemblage, from each of the localities. They went on to stress that variation was due to actual shape preference and not just to size differences, which, to some extent, negates both raw material and reduction theories and places increased emphasis on the presence of socially transmitted macro-regional differences.

The presence of variation in form on a macro-regional level i.e. Africa, Europe, India, as selected by Lycett & Gowlett (2008) could well have been the result of drift or idiosyncrasy. Whether differences only apparent over such a wide spatial range are representative of variation in Acheulean culture, is still an idea open to question, and one where the answer is likely to be, one of degree. The established notion that conservative levels of cognition governed tool form is certainly born out when regarding the handaxe as a single typological form defining a monolithic industry; a traditional viewpoint espoused by Clark (1994:

454), Klein (1999: 337), Schick & Toth (1993: 283), Tattersall *et al* (1988: 4), and others. However, there has been a softening of opinion reflected by studies which illustrate the existence of technical variation in Middle Pleistocene Acheulean assemblages (Lycett, 2009; Sharon, 2007; 2009; Sharon & Beaumont, 2006) and morphological variation in handaxe form (Gowlett, 2005; Lycett & Gowlett, 2008; Wynn & Tierson, 1990). Much of this variation is again regional in nature and does come with the ecological caveat that, as discussed (section 5.3), available raw material differs by region and likely had an impact on the initial form of handaxes produced. Despite such caveats, handaxe production does require the hominin imposition of arbitrary form on any type of raw material and as such, the techno-stylistic *savoir–faire* necessary to impose such form would require transmission from experienced, to novice knapper. The passing on of skill therefore requires the operation of some form of cultural transmission. The type and degree of that transmission and its effect on lithic form and rate of change is however, archaeologically difficult to prove, especially for the Acheulean of the Middle and Lower Pleistocene.

The issue of differing regional handaxe shapes as the result of a culturally transmitted tradition was also explored by Wynn & Tierson (1990). Based on a sample of 1,178 handaxes from 17 sites representing Europe/UK, East Africa, India and the Near East, Wynn & Tierson (1990) used a system measuring polar co-ordinates, from a midpoint to 22 separate points all the way around the circumference of each handaxe. To compensate for size differences, allowing for focus to be purely on shape, a correction was applied to each polar measurement by dividing it by the length of the handaxe. Discriminant analysis (multi and univariate) and *ANOVA* were used to compare the polar shape groups against a null hypothesis that there would be no difference in shape. The analysis shows that whilst Indian handaxes did not stand apart, there was distinct variation displayed by Near Eastern handaxes and specific groups of African and English handaxes (p79-80). To rationalise this, Wynn & Tierson (1990: 81) acknowledged the effect of raw material on handaxe shape, citing the experimental work of Jones (1979) and also running their own discriminant function analysis on the handaxes from Kariandusi, which allowed them to classify, from the analysis, 75% of the sample according to the actual raw material type (albeit only lava and obsidian, both materials with very distinct knapping properties that would likely produce well-defined and easily separable forms). The point of this exercise was to acknowledge the effect of raw material constraints on form but with the proviso that ecological factors do not account for all variation, and certainly do not preclude the existence of differences in culturally generated form and cultural transmission on a macro-regional basis.

In an earnest attempt to identify variation as the product of deliberate action by individual knappers, Gowlett (2005) studied a range of bifaces from localities at Kilombe, Kenya. His focus was on the individual within the group, and identifying the level of variation that was acceptable within the established techno-cultural norm of that group. In this scenario, a system like Wynn's (1995) 'effortless reflexivity' (discussed above) could have been used to establish those norms. Gowlett (2005: 53) used cluster analysis of surface artefacts to identify morphometric similarity, thereby inferring cultural coherence, together with extremities which may point to group and individual action respectively. At the same time, he commented on the fact that often used statistical procedure, focusing on standard deviation and mean based analysis, can have the effect of averaging variation, instead of highlighting it. The Kilombe data centred around two sets of highly clustered bifaces: a large set and a small set. Gowlett (2005) positioned the size differences against the backdrop of Gowlett (1988) where the large set was aligned with the Acheulean and the small set with the Developed Oldowan B, which at Kilombe co-occurred to a much higher degree than at Olduvai (the type site), leading Gowlett (1988: 22) to conclude that they were not separate traditions. Clustered within the large set was a group of 6 unusually thin handaxes which accounted for between 50% and 66% of variability of the AC/AH group at the GqJh1 site locality. As well as being thinner i.e. having $\frac{Th}{B}$ ratio that was lower than both large and small groups, the group of 6 were also more ovate in shape than the pointed norm. Any suggestion of allometric scaling as a reason for not attributing ratio and shape differences to distinctive individual knapping style was discounted on the basis that ratios did not plot on the trends of allometric scaling produced in Crompton & Gowlett

(1993). On this basis, these handaxes likely represent the work of a distinct and skilled individual displaying a learnt, practiced and honed technique.

Within the small set of handaxes, individual levels of variation were greater than for the larger set; the implication here is that larger handaxes had to adhere to a tighter template of acceptability or group norm. Gowlett (2005) also compared these archaeological levels of variation with those achieved in an ethnographic setting (see Stout, 2002a), where the consistent output of a competent knapper could also account for over half the variation of the wider group. At this point Gowlett (2005) only makes passing comment on skill levels and modes of transmission such as the apprentice/master-craftsman scenario and does not discuss these factors as viable conduits of cultural variation. In an attempt to test ideas of variability (or stasis) across the Acheulean spatial and temporal scale, Gowlett (2005) also looked at bifaces from Beeches Pit, a Middle Pleistocene site in England. The wider levels of variability in the entire site were marked, but again, in one specific area (AF), there were two standardised examples of small handaxe forms that could have been knapped by the same individual. The whole Beeches Pit scenario is once more accounted for as showing elasticity within a wider group norm where it was acceptable to exceed those norms in the case of one or two morphometric variables but not in all of them. Gowlett (2005: 66) concluded by surmising which set of boundaries first created this situation: functional or cultural? However, what Gowlett (2005) did not properly consider was the attribution of individual and group variation to differences in skill and methods of cultural transmission and more importantly, the likely mechanisms that allowed (or not) those differences to occur, over restricted or extended temporal and spatial ranges.

5.7 Discussion and structure of Acheulean transmission chain experiments.

As discussed in section 5.3, theories positioning raw material as the sole factor for explaining lithic variation were born from dissatisfaction with typological systems that are ecologically and statistically unsound in the way they classify artefacts. It is clear that variation exists on a continuum and placing artefacts into diametrically opposed groups based on two dichotomous descriptors such as 'point' and 'ovate' will always have the effect of polarising the way in which assemblages are viewed, thus distorting the ability to produce balanced interpretations. Raw material is likely to influence the initial stages of artefact production but once the choice of nodule/core has been made, variation is created by subsequent stages in the *chaîne opératoire*; a point readily highlighted by McPherron (1995) from his reworking of Roe's original dataset (section 5.4). By moving the emphasis of causes of variation away from theory constrained by both raw material and culture history, McPherron placed increased stress on behavioural aspects of variation, based on reduction and resharpening strategies, primarily related to resharpening of the tip or distal cutting edges of the handaxe, in preference to more proximal areas closer to the butt. This change of approach is to be commended but where McPherron's theory seems to lack cohesion is with regard to the idea that, as a result of resharpening, handaxe form tends to shift from pointed to ovate. On this basis, he assumes that all handaxes follow the same reduction and usage trajectories, a fact that discard of handaxes in differing stages of their putative life-cycle would tend to disprove. A key determinant of variation mentioned in only the most cursory of manners by exponents of both the raw material and reduction theories is that of taphonomy, or variation in form unintended by the original knapper. Grosman *et al* (2011) and their experimental reconstruction of post-depositional rolling clearly demonstrated the speed with which taphonomic factors can change the pristine form of a handaxe. This was notable in the early stages of the taphonomic process for the planform profile, which ultimately defines the degree of pointed or ovateness, and then changes in volume and symmetry in more extended cases of rolling. It is this type of approach that further emphasises the danger of forming conclusions, ecological or behavioural in nature, when the excavated dataset may be substantially different from the artefact form or assemblage composition that originally entered the archaeological record.

The regional case studies described above, present examples of handaxe variation that may be the result of factors not directly attributable to the theories of raw material, function and reduction. If the models of Powell *et al* (2009) are correct, in their suggestion that a critical mass of population density, group size and mobility has to be reached (within the same species and assuming cognitive parity), before certain cultural grade shifts are enabled, then ideas on how the small groups of Lower and Middle Palaeolithic hominins impacted on Acheulean handaxe form needs to be explored using experimental archaeology. The work of Gowlett (2005); Lycett & Gowlett (2008) and Wynn & Tierson (1990) is strongly suggestive of skilled individuals creating stylistic variation within the confines of a tool form that was tightly regulated either by a ceiling in cognitive ability, or a culturally constrained norm in handaxe form or *chaîne opératoire*. Although undertaken with fully modern *Homo sapiens*, TC experiments are ideally placed to undertake such experimentation. Under laboratory conditions, protocol can be tailored towards exploring different aspects of Roe's (1968) typological organisation, the raw material and reduction theories forwarded by Ashton and McNabb(1994) and McPherron (1995) respectively, and the transmission theories mooted by Shennan & Steele (1999) and Lycett & Gowlett (2008). With these issues in mind, Table 5.1 summarises the objectives and approach taken by the next set of TC experiments, which have been designed to explore the issues discussed above.

Expmnt	**Objectives and focus of each Acheulean transmission chain experiment**
All	To use and evaluate Roe's system of metrically based ratios as tools for measuring and evaluating handaxe variation caused by differing TCPs. To develop new systems of measurement or analysis when Roe's metrics fail to adequately capture variation caused by the different transmission chain biases operating in Experiments 2, 3 and 4 respectively.
2	When subjected to multiple generations of copying, to what extent do classic ovate and pointed handaxes drift into one another? Can pointed handaxes become ovate as a result of stylistic drift? Are they handaxe forms on a continuum of variation or are they distinct etic types? What levels of inter-generational variation were produced when the TCP was focused on uninstructed end-state copying?
3	What levels of variation were produced when TCP was focused on one-to-one expert instruction from a cultural parent?
4	What levels of variation were produced when TCP focused on accomplished peer group instruction in a 'many-to-one' environment?

Table 5.1. Objectives and focus of TC experiments 2, 3 and 4.

This experimental programme (Table 5.1) was designed to replicate and explore some of the different biases and cultural transmission scenarios laid out in Figure 2.9. By using the cohort of trained flint knappers, transmission chain theory can be used to ascertain the effect different group structures or transmission types have on handaxe form over multiple generations of copying. The objective was to produce experimental data, in a controlled environment, measured in the first instance by the metrical points of Roe (1968), as illustrated in Figure 3.14. This formed the basis of the process designed to help verify likely levels of variation caused (or allowed) by the different types of transmission bias replicated in each of the individual experimental conditions. In reality, cultural transmission during the Palaeolithic was likely more complicated than this. A fact demonstrated by transmission among contemporary (non-human) primate groups (Matsuzawa 2011; Whiten *et al* 2005) and also contemporary small-scale human societies in Fiji (Henrich & Broesch 2011) and Iran (Tehrani & Collard 2009). In each of these analogous scenarios, socio-cultural learning involved combinations of the types of transmission highlighted above (Table 5.1), at different points in the life-stage of offspring or apprentice craft workers and not single types of transmission in isolation. With this in mind, the objective of this experimental programme is to create TCPs that facilitate a base-line understanding of the effects of individual biases or transmission types, to help inform understanding on the cultural transmission process.

Chapter 6.

Experiment 2: the effects of copying error from uninstructed end state copying on ovate and pointed handaxes in transmission chains

6.1 Introduction

Experiment 1 (Chapter 4) confirmed that artefact form, both metric and non-metric, can vary as it is transmitted between generations. For the metric attributes, when subject to uninstructed end-state copying or guided variation (the transmission bias used in that experiment), aspects of that variation were confirmed as statistically significant. In terms of Acheulean handaxe form and the longstanding archaeological issue of variation within a conservative or constrained tool form (Chapter 5), this raises two main questions:

- What transmission biases or processes of skill transmission are implied by the persistence of such ‘preferred’ lithic forms found in the Palaeolithic record?
- Why did some of these preferred Palaeolithic stone tool forms remain relatively unchanged not just over a few generations, but for much more extended periods (sometimes many millennia) and over such wide spatial ranges?

The knapping task explored by Experiment 2 was designed to focus on the evolution of ovate and point-form Acheulean handaxes and the longstanding issue in Lower Palaeolithic archaeology, that of accounting for levels of variation within those broad classes of handaxe form. The types established by Roe (1968) classified handaxe sites or assemblages on a typological basis according to the arbitrarily decided 60% presence of ovates, point-forms or cleavers, an allocation that represented the basis of a culture-evolutionary explanation for variation in handaxe form. Other dominant theories (discussed in Chapter 5), accounting for such variation and their main exponents are as follows: raw material and function (Ashton & McNabb, 1994; White, 1998) and reduction (McPherron, 1995). Within these theories, little credence was given to the possession of skill, transmission of skill or copying error as factors able to generate different levels of variation in the production of material culture, on a temporal or spatial scale.

Subsequent theories positioning population density (Lycett & von Cramon-Taubadel, 2008; Powell *et al,* 2009) and social transmission (Lycett & Gowlett, 2008; Shennan & Steele, 1999) have addressed demographic and neo-Darwinian issues of cultural evolution used in psychology (Boyd & Richerson, 1985; Mesoudi, 2011), but have yet to consider such socially produced variation in the context of experimental archaeology. In the context of the following experiments, this involves the production of handaxes by multiple generations of contemporary knappers, forming part of tightly controlled transmission chain protocols. It is the production of Palaeolithic artefacts, using archaeologically attested techniques in a micro-evolutionary context, which is currently missing from macro-scale demographic theories. This research helps to bridge that gap and enable exploration of the effects on artefact form of random stylistic drift and the mediating effect of cultural transmission biases. In Experiment 2, guided variation or uninstructed end-state copying (Caldwell *et al*, 2012), with no communication between generations, formed the basis of the transmission chain. By using this TCP, it was hoped to replicate likely Palaeolithic group conditions where there was no formal structure in place to instruct in the knapping process or enforce and select adherence to specific attributes or attribute combinations when copying the specified target form. In this scenario, where none of the participants was a knapping expert, and where skill levels were at competent novice level (section 3.4.2), the idea was to mirror demographic conditions (section 5.5 & 5.6) where hominin group size was small and there were low levels of both inter and intra-group contact. This would therefore minimise the likelihood that skill levels would improve from any form of instruction, and innovative changes in form would be less likely to ratchet and be consistently passed on through the transmission chain. Variation (or lack of) and iterative form changes, in this scenario, would likely be the product of drift/perceptual deficiency or insufficient skill, thereby forming a base line to measure the effect of other transmission biases against.

6.2 Objectives

In the broader context of the whole series of Acheulean experiments described in the following chapters, the objective was to refine current understanding of the periods of stasis in the production of particular Palaeolithic tool forms, specifically the handaxe (Clark, 1994: 454; Clark, 2001a: 1; Klein, 1999: 337; Schick & Toth, 1993: 283), and to formulate theories that help explore likely shifts in transmission techniques that are able to account for temporal or spatial changes in the production of lithic technology (see Chapter 9 for comparisons and discussion of each experimental condition and conclusions in Chapter 10). In the first instance, for all experiments, the metrics established by Roe (1968) were used to quantify variation in handaxe form. Building on the Roe metric system, new evaluation techniques, focusing on geometric use of linear data and area based measures derived from imaging software, were also employed. Specifically related to Experiment 2 (the first of the Acheulean experiments), the primary objectives were:

- To examine how ovate and pointed handaxes, as defined by the Roe typology (1968) evolved through the multiple generations of a transmission chain, subject to uninstructed end-state copying and guided variation.
- To explore the degree to which copying error (random stylistic drift) or conversely, change of a more directional nature likely caused by insufficient skill, affected the form of each type of handaxe.
- To determine whether handaxe form is partially etic in nature and to discover the extent to which typology may actually drift between the ovate and pointed forms defined by Roe. A potential outcome could be that handaxe form was not exclusively a product of raw material, reduction or function. Skill, transmission and copying error may well have played a role in the creation of pointed or ovate variation, which was not the product of deliberate intention. That is, there was no thought on behalf of the knapper to produce a new form; it was merely a poorly copied version of the original target form. The degree to which this

process occurred could potentially affect the speed with which artefact form changed or remained in stasis.

- As a secondary and alternative hypothesis to McPherron’s idea on ovates being reduced pointforms; when subject to uninstructed end-state copying, would a pointed target form become ovate, after multiple generations of copying? Could this be an explanatory factor for the difference in pointed and ovate form, as opposed to ovates being purely reduced versions of pointed handaxes?

6.2.1 Target Form

Two target forms were selected for the TCs of Experiment 2. Target form one was an ovate handaxe (Figure 6.1a) with the following (maximum) dimensions: length 146mm, width 103mm and thickness 23mm.Target form two was a pointed handaxe (Figure 6.1b) measuring 175mm long, 85mm wide and 26mm thick. These forms were chosen because they represent extremes of the Roe typology (1968).

Figure 6.1a. Base ovate target form.
Photograph: S. Page

Figure 6.1b. Base pointed target form.
Photograph: S. Page

Roe's (1968) theory of a linear progression from one etic form to another, point to ovate in this case, was refuted by the archaeological interstratification of handaxe types, which acted as a challenge to culture evolutionary accounts of inter-site and intra-assemblage variation. By 1981, Roe himself seemed to be softening on his original ideas as way of classifying Acheulean assemblages, when he stated, "There seems accordingly, no justification when considering Britain as a whole, for referring to a 'Middle Acheulean with pointed handaxes' followed by a 'Later Middle Acheulean with refined ovates', as has sometimes been done in the past" (Roe, 1981: 203). To supersede this, he advocated subsuming variation into a long Middle Acheulean, followed by a statement where firstly, he declined to consider raw material as a contributory factor and secondly, gave only cursory mentions to skill and local knapping tradition as possible factors accounting for variation. In this context, Roe had created a credible set of handaxe metrics but failed to use them to address issues that likely created the variation his measurement system highlighted so effectively. To deal with these shortcomings, the target forms of Experiment 2 were chosen with the purpose of contributing understanding to the idea that one form may drift into the other; point to ovate for instance, or vice-versa, over multiple generations of copying. This presents the idea that different handaxe shapes could have been a product of the ebb and flow of small, hominin groups where variation in form was generated by uninstructed end-state copying and not the deliberate intention to produce a specific type of handaxe form.

6.3 Methodology

6.3.1 Transmission Chain Protocol

Centred on Acheulean technology, to produce conditions of uninstructed end state copying (Chapter 2), Experiment 2 required that members of the knapping cohort formed two, single member, multi-generation transmission chains: TC1 (n=7 generations) and TC2 (n=8 generations). The first member of each TC received the base target form (as prepared by the examiners): for TC1 that was the ovate handaxe and for TC2, the pointed handaxe (Figures 6.1a & 6.1b).

Each knapper received two standardised, porcelain preform handaxe cores (sections 3.2.5 – 3.2.7) and was instructed to knap two copies of the target form handaxe, replicating that form as exactly as possible; the target form was available to view and handle for the entire duration of each knapping session. The knapper was then told to select what they felt was the closest facsimile; this became the target form for the next iteration and so on, through each generation until the TC was completed. Each knapper had to produce at least one copy of the target form per knapping bout, so if both preform cores broke during the reduction sequence (possibly due to end-shock), then the knapper would be supplied with a new preform to ensure continuance of the TC (a situation that never occurred).

Skill assessments were conducted to ensure that all knappers participating in the experiment had reached the appropriate level of skill, commensurate with the production of Acheulean handaxes and to ensure the realistic continuance of each transmission chain (see section 3.4.2 for full procedural details). Due to the different aspects of reduction involved in the handaxe production procedure, such as shaping, thinning and edging, a key difference between Experiments 2 - 4 and Experiment 1 was the selective use of different hammerstones. In Experiment 1, all participants of both TCs used the same hammerstone, to ensure direct focus on the physical and cognitive aspects of knapping skill. For Experiment 2, they were able to choose from 6 different hammerstones (Table 6.1), which were selected by the experimenters as appropriate for achieving the different aspects of handaxe production mentioned above. Hammerstone selection is a key aspect of knapping skill and is as important a factor in the knapping process as mastering the bio-mechanical control necessary for certain flake removals and artefact shaping (pers. comm. Bruce Bradley 06/04/12). In this respect, it was considered that hammerstone selection was a variable open to the personal choice or input of each knapping generation.

No.	Wt (g)	Description & shape	Texture
1	312.7	Elongated with one end wider than the other	A rough, gritty red sandstone
2	209.1	Spherical but smaller than h'stone 6	Fine grained
3	157.6	Smaller and more tube like than h'stone1	A rough, gritty red sandstone
4	445.6	Large and spherical	Gritty sandstone
5	385.4	Largest size but flatter (and lighter) than h'stone 4	Bigger softer grains than other h'stones
6	296.2	Sub-spherical, thinning towards one end. Smaller than h'stone 4	Fine grained

Table 6.1. Hammerstones available to the Ex2 TCs, providing each knapper with a choice of different weights, shapes and grain size.

The following sections assess whether Roe's measurement points and ratio based analysis system were effective tools for examining handaxe variation produced as a result of the transmission chain protocol employed by Experiment 2. To begin, it used Roe's standard dimensional measures followed by refinement and shape ratios, before moving on to explore different types of metric analysis such as handaxe taper and 3D Euclidean shape measures, that can be employed by using the standard dimensions already taken as part of the Roe methodology. Building on these measures of iterative form change, away from the base target forms of each TC, this chapter will also explore variation in levels of handaxe symmetry, total planform handaxe area, residual cortex area and total edge or handaxe profile area as additional proxies of culture evolutionary change in handaxe form. Those measures were achieved by using Flip Test software for calculating measures of asymmetry and ImageJ (digital measurement and analysis software), for area based measures (sections 3.5.9 & 3.5.7 respectively). Establishing the procedure and standard scales needed to produce accurate measurements from 2D photographs (used by ImageJ) of the handaxes produced by the knappers of all TCs in this project, starting with TC1 and TC2 of Experiment 2, was also explained in the methodology chapter (section 3.5.8).

6.4 Results drawn from Roe metrics

6.4.1 Basic dimensional measures

The basic handaxe dimensions used were the measures of maximum length, width and thickness (described in methodology section 3.5.5 and accompanying Figure 3.14). As handaxe production is reliant on a process of *Façonnage* or shaping of the blank (Inizan *et al,* 1999; Gallotti *et al,* 2010; Sharon, 2010), which is essentially a reductive process, the hypothesis or expectation for both ovate (TC1) and pointed (TC2) transmission chains was that variation, driven by uninstructed end-state copying, would result in the cumulative shrinkage of all key dimensions as they progressed through the generations of the TC. Initial inspection of the dimensional attribute data revealed that the same transmission bias (uninstructed end-state copying) affected the progress of the target form differently in each TC. For the ovates of TC1, the performance of breadth was erratic and random. For length, there appeared to be slight directional movement towards the knapping of a longer handaxe through the generations of the TC. However, despite this seeming behaviour, relationships or trends for all dimensions were weak and lacking in significance: length $R^2 = 0.469$, $p = 0.06$; breadth $R^2 = 0.0075$, $p = 0.84$; thickness $R^2 = 0.413$, $p = 0.09$ (Figure 6.2). In contrast and in line with the hypothesised generational loss of length, for the pointed handaxes of TC2, there was a significant trend as handaxes became progressively shorter ($R^2 = 0.884$, $p = 0.0002$). For breadth ($R^2 = 0.0069$, $p = 0.83$) and thickness ($R^2 = 0.0002$, $p = 0.97$), there was less of a relationship between the generational progress of TC2 and the knapped dimension of the handaxe, than there was in TC1 as dimensions appeared to remain relatively static (Figure 6.3).

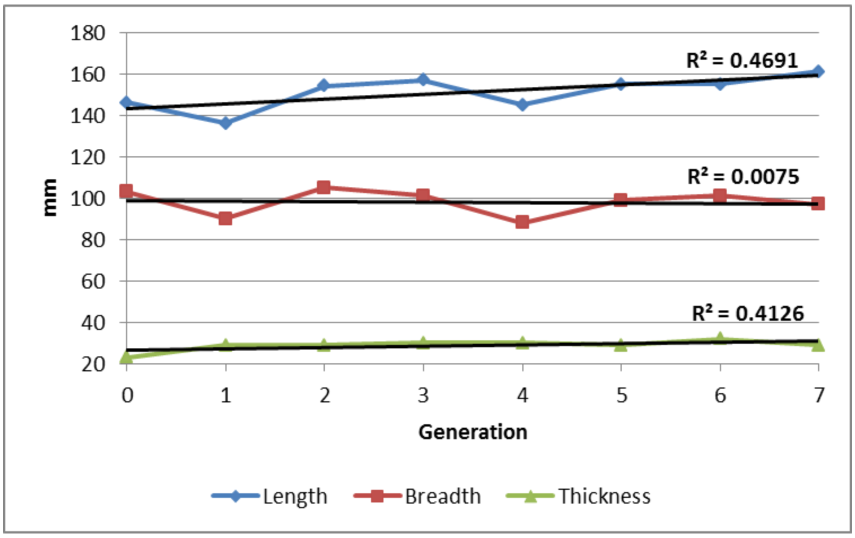


Figure 6.2. Trajectory of basic linear measurements for the chosen ovate forms passed through TC1 (length, *p* = 0.06; breadth, *p* = 0.84 and width, *p* = 0.09).

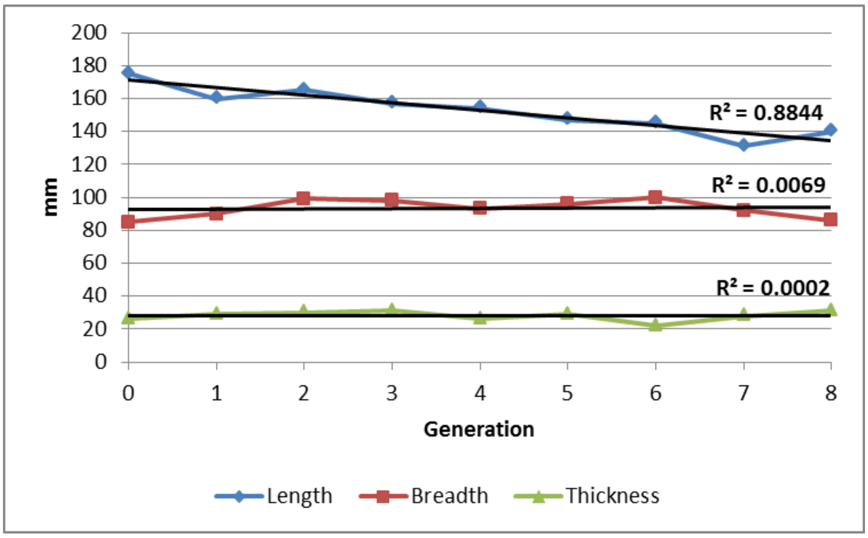


Figure 6.3. Trajectory of basic linear measurements for the chosen pointed forms passed through TC2 (length, *p* = 0.0002; breadth, *p* = 0.83 and width, *p* = 0.97).
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With the exception of reduction in length for the points of TC2, analysis based on basic dimensions gave the impression that handaxe attributes were being replicated and transmitted accurately and that form was not changing in a substantial way. However, with regard to evaluating the objectives of overall form change related to skill, or the drift of form between the two extremes of point and ovate, the single dimensional measures of length, breadth and thickness provided little real indication of changing morphology. This is especially true when considering how variation in one dimension affects its relationship to other dimensions, impacting on the overall shape of the piece; a key factor in handaxe production due to the reductive and interlinked nature of the knapping process. The following sections evaluate handaxe form from the perspective of refinement and shape, using the system of ratios developed by Roe (1968), to gain a more complete idea of changes in handaxe shape.

6.4.2 Refinement ratios

In the first instance, Roe's metrics were used to ascertain the effect of uninstructed end-state copying on the refinement of each target form, in each transmission chain. Refinement (or flatness) was gauged by two ratios, maximum thickness divided by maximum width ($\frac{Th}{B}$) and thickness at T1 divided by length ($\frac{T1}{L}$). Both ratios were used for pointform and ovate handaxes (as opposed to Roe's application of $\frac{T1}{L}$ solely to pointed handaxes). Figure 6.4 shows all handaxes knapped by the ovate producing TC1 and Figure 6.7a, the path of the target form as it passed through each generation of the TC. Figures 6.5 and 6.7b show the same relationships but for the pointed handaxes of TC2. In these figures, the initial or base target form of each TC was highlighted in red. In the first instance, the general pattern of all handaxes knapped in each TC is discussed, before the actual trajectory of each respective chain.

It was expected that overall levels of refinement would not match those of the base target form, in either transmission chain, due to the uninstructed nature of the TCP. It was also expected that this situation would be aggravated further, due to being the first handaxe experiment and consequently, levels of skill were still relatively low. The scatter of all handaxes in the ovate chain (TC1) was distinct from that of the pointed TC2; all ovates had a maximum thickness relative to breadth ($\frac{Th}{B}$) greater than the 0.233 of their base target form, whereas, for the pointed handaxes of TC2, there was a spread of values around the base target form $\frac{Th}{B}$ ratio of 0.306 (Figures 6.4 & 6.5 respectively). When the linear nature of the relationship between the copying generations and each of the refinement attributes was analysed using R^2, only $\frac{T1}{L}$ registered a significant relationship, and only in TC2 ($R^2 = 0.61$, $p = 0.013$, see Figure 6.6). This was likely linked to the levels of skill required, deficient in this case, to shape and thin the tip of a pointed handaxe, whilst simultaneously maintaining overall length. For $\frac{Th}{B}$, despite the increasing thickness shown in Figure 6.7a and 6.7b, it did not register as a significant trend for either type of handaxe. On this basis, only in the TC2 relationship was significance strong enough to suggest that pointed handaxes were becoming less refined over time as a direct result of low skill levels, in a TCP subject to uninstructed end-state copying.

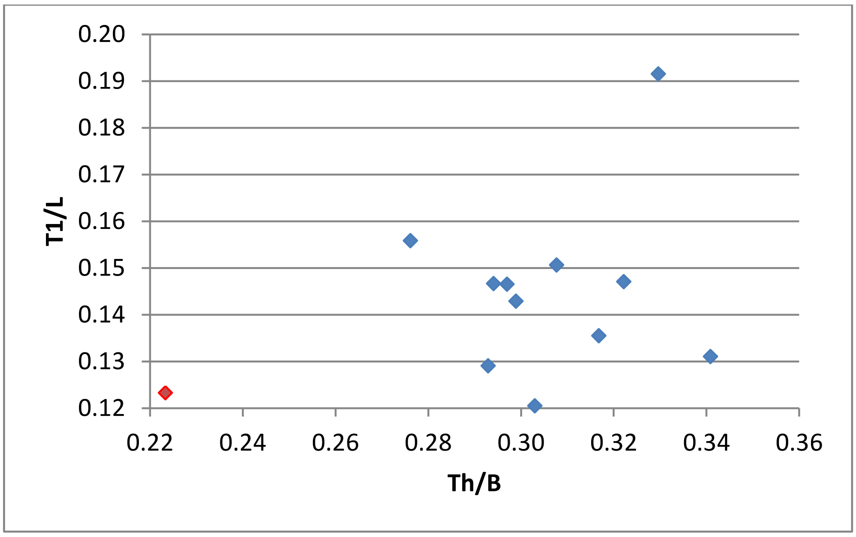


Figure 6.4. Scatter of all handaxes in TC1 for refinement measures $\frac{Th}{B}$ and $\frac{T1}{L}$.

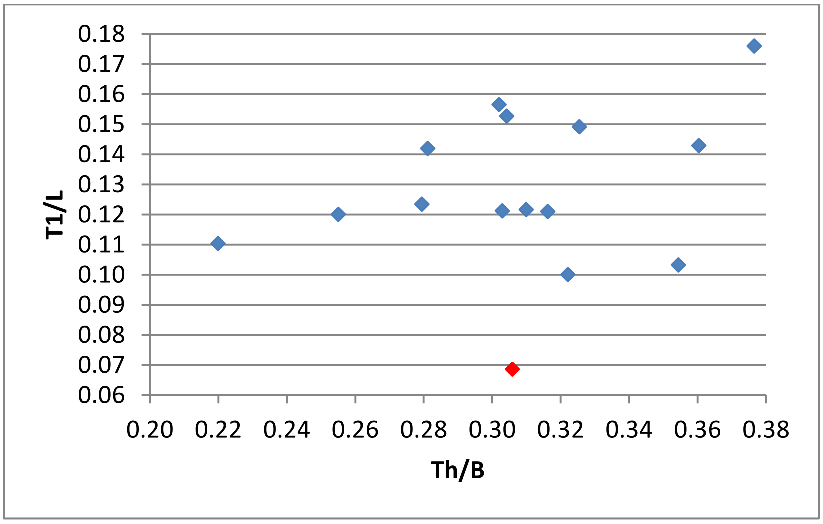


Figure 6.5. Scatter of all handaxes in TC2 for refinement measures $\frac{Th}{B}$ and $\frac{T1}{L}$.

In the context of a transmission chain governed by uninstructed end-state copying, overall handaxe thickness and tip thickness of the pointed handaxe appeared difficult to transmit on an inter-generational basis, when there was no verbal or visual contact between the knapping generations. When the 'refinement' data points $\frac{T1}{L}$ and $\frac{Th}{B}$, (representing the achievement of each knapper), were viewed together and joined by a line indicating the sequence or chronological order of the generations, starting with the red marked base target form and following the line to the end marked with the directional arrowhead (Figure 6.7a and 6.7b), it further illustrated that variation was extensive but that no real trend was apparent. Each knapper appeared not to possess the skill to replicate the required combination of both refinement measures simultaneously.

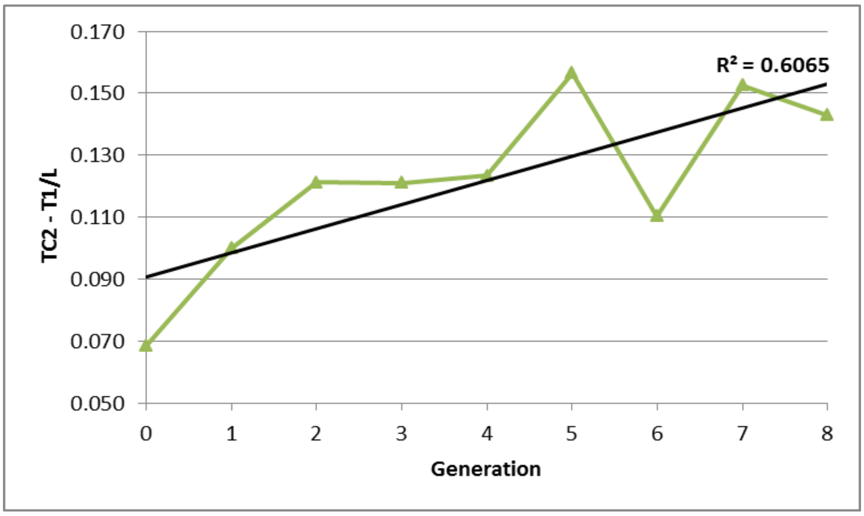
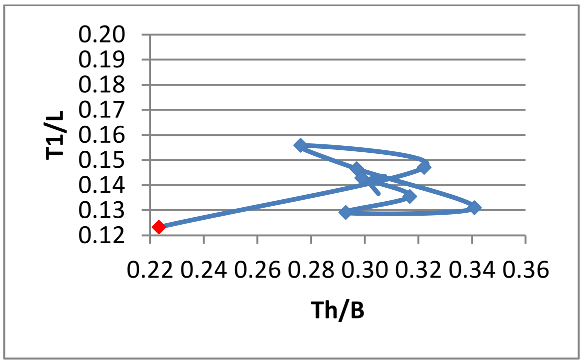


Figure 6.6. $\frac{T1}{L}$ (TC2), the only statistically significant refinement measure (p = 0.013).



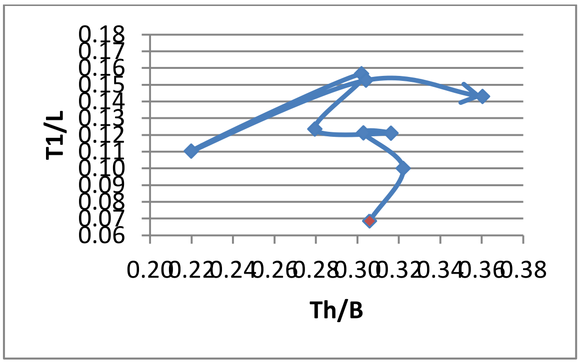


Figure 6.7a. TC1 path of chosen ovates. Figure 6.7b. TC2 path of chosen pointforms.

The lack of cohesive and significant transmission of the Roe refinement measures suggested two other possible scenarios: firstly, other factors such as shape measures were taking preference in the TCP of Experiment 2 or, other refinement attributes not captured by Roe's metrics (such as levels of cortex as a proportion of surface area), were transmitted in preference to handaxe tip thickness. These issues will be considered separately in the following sections.

6.4.3 Shape measures

To discover if uninstructed end-state copying affected shape characteristics in the same manner as the refinement attributes, and specifically to judge whether the ovate and pointed forms of each respective TC became less distinct, the planform shape of the ovate handaxes (TC1) and the pointed handaxes (TC2) was measured using Roe's three ratios: $\frac{B}{L}$ (breadth over length), $\frac{B1}{B2}$ (breadth at 20% of length over breadth at 80% of length) and $\frac{L1}{L}$ (length from the butt to the widest point of the handaxe, over length). In all cases, the relationship between the $\frac{B}{L}$ ratio (highlighting the possible connection between maximum breadth and length), was plotted against the more specific measures of $\frac{B1}{B2}$ and $\frac{L1}{L}$ (section 3.5.5). The issue of how handaxe size (area in cm^2), in each TC was affected by the simultaneous achievement of other attributes, and related to knapping skill, is discussed in section 6.9.2 onwards. In each of the following charts, the base target form copied by the first knapper of each TC is highlighted in red.

As was the case with refinement measures, it was expected that the shape ratios would also indicate a breakdown in handaxe form, as a result of multiple generations of copying in a transmission chain. The decreasing $\frac{B}{L}$ ratios of Figure 6.8 show that all ovates produced became narrower relative to length, indicating the difficulty of reproducing and maintaining the length/breadth relationship for all knappers, even when working with standardised raw material. Analysis of the Roe shape attributes for the chosen forms of each TC (Figure 6.9) revealed that for $\frac{B}{L}$ and the ovates of TC1, the trend towards narrower handaxes relative to length, on an intergenerational basis was relatively strong (R^2 = 0.6146, p = 0.02), indicating a significant relationship and one that likely reflected the struggle experienced by the knappers when trying to maintain one of the main axial relationships of handaxe shape. For TC1, that struggle was affected most by the rise in length from 14.6cm to 16.1cm (Figure 6.2) , as the form moved away from the original ovate shape towards the longer narrower form indicated by the $\frac{B}{L}$ trend line below (Figure 6.9).

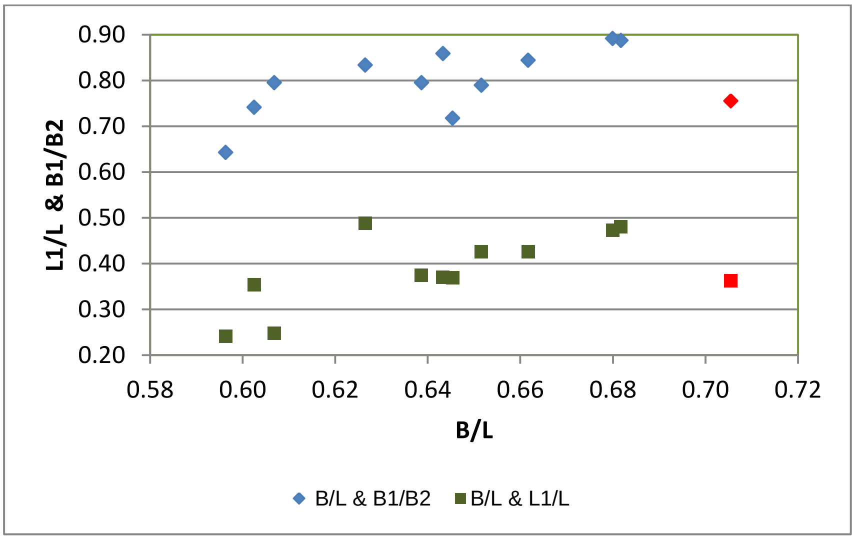


Figure 6.8. All TC1 ovates were narrower relative to length and displayed difficulty in managing the ovate nature of the form, measured by the variance in $\frac{L1}{L}$ and $\frac{B1}{B2}$.

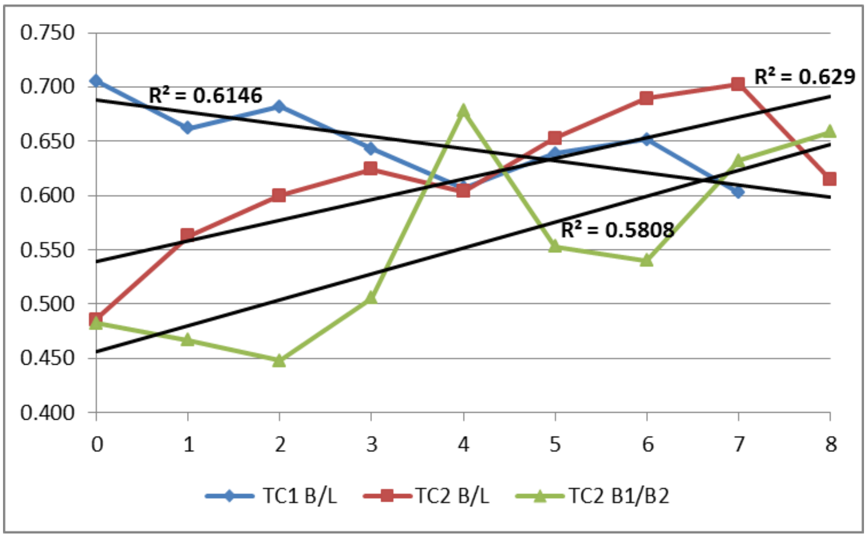


Figure 6.9. Statistically significant relationships found using Roe shape measures for TC1 ($\frac{B}{L}$, p = 0.02) and TC2 ($\frac{B}{L}$, p = 0.01; $\frac{B1}{B2}$, p = 0.017).

Although $\frac{B}{L}$ was the only significant relationship in TC1, the largest levels of inter-generational variation, ranging between 0.248 and 0.481, were displayed by the $\frac{L1}{L}$ ratio, measuring where the widest point of the handaxe was relative to its length; a key measure of shape and the knappers' ability to maintain and reproduce either the ovate or point form that he/she was presented with. In this instance, the $\frac{B}{L}$ trend towards narrower handaxes (relative to length), was accompanied by both positive and negative inter-generational variation in $\frac{L1}{L}$, illustrating a further breakdown in the accurate transmission of form and the limited control knappers possessed over $\frac{L1}{L}$ and handaxe shape, when subject to uninstructed end-state copying (Figure 6.10).

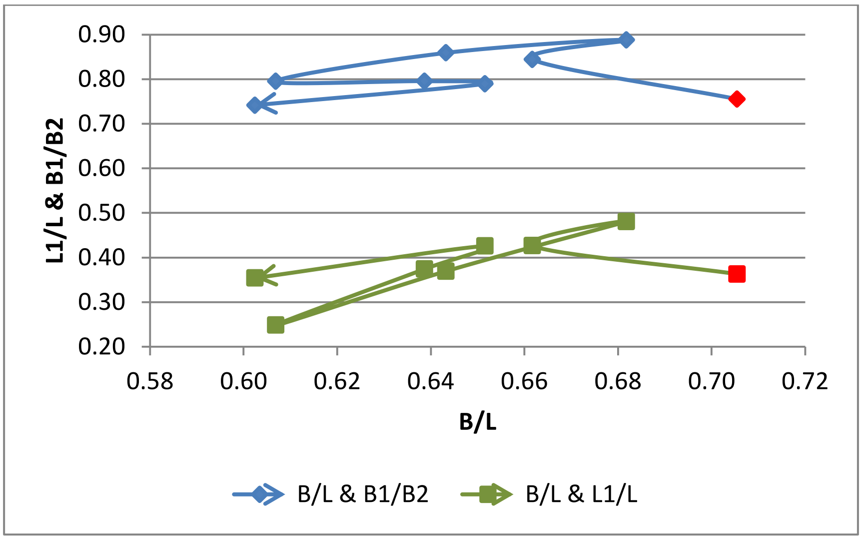


Figure 6.10. TC1 chosen ovate handaxes by knapping generation. All attribute measures varied in each iteration, resulting in the distortion of the ovate form in every generation, throughout the duration of the TC.

For the pointed handaxes of TC2, the expected breakdown in transmission of shape was more extreme than expected. All $\frac{B}{L}$ ratios scored higher than the 0.486 of the base target form (Figure 6.11a), illustrating a characteristic where handaxes became wider relative to length; a completely converse and more pronounced characteristic than that shown by the $\frac{B}{L}$ variation of the TC1 ovates (Figure 6.8). On an inter-generational basis, for the handaxes chosen to pass through the transmission chain (Figure 6.9), the TC2 trend for $\frac{B}{L}$ to demonstrate the knapping of increasingly wider, shorter handaxes, was statistically significant ($R^2 = 0.629$; $p = 0.01$). This change was accompanied by an indication that pointed handaxes were also becoming less tapered and thus more cordiform over time with a significant increase in $\frac{B1}{B2}$ as the copying generations progressed ($R^2 = 0.58$, $p = 0.017$). To help illustrate the linear trends and loss of defining point and ovate attributes indicated by Figure 6.9, as well as length for the points of TC2 (see section 6.4.1), Figure 6.12a and 6.12b show the physical difference between the base target forms of both TCs and the more cordiform shape resulting from 7-8 generations of transmission. See Appendix 4 for photographs of all chosen forms, by transmission chain.

Closer examination of all ratios (Figure 6.11b), shows how the $\frac{B1}{B2}$ shape ratio remained relatively stable for 2 or 3 iterations, remaining between 0.45 and 0.5, before the higher ratios of the latter generations indicated the emergence of a less defined point shape. Although not a significant trend ($R^2 = 0.13$, $p = 0.34$), this pattern was born out in the $\frac{L1}{L}$ ratios, where, with the exception of iteration 1, all subsequent generations scored above the 0.2 of the base target form. This again illustrated inability to manage handaxe shape, resulting in a movement of the widest point of the TC2 handaxes, up their length, away from the butt, thereby reducing the essential pointedness of their nature.

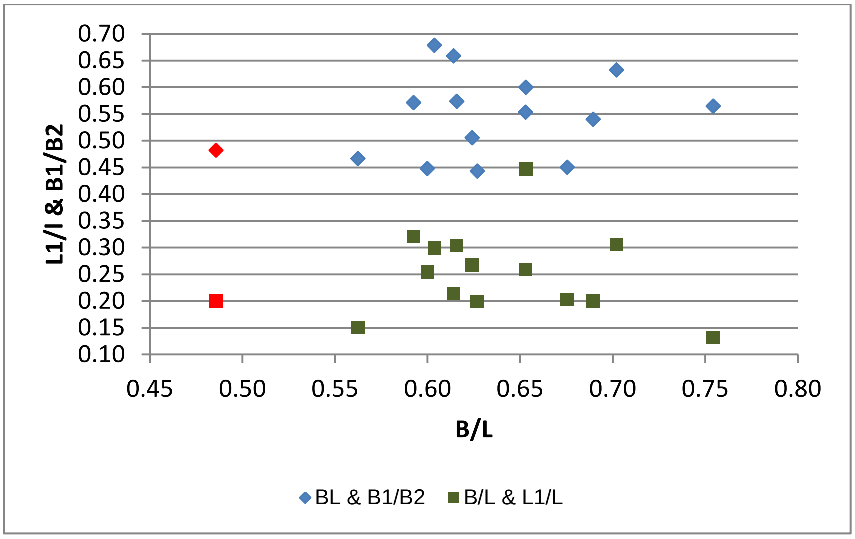


Figure 6.11a. TC2 scatters of all pointed handaxes plotting $\frac{B}{L}$ against $\frac{L1}{L}$ and $\frac{B1}{B2}$.

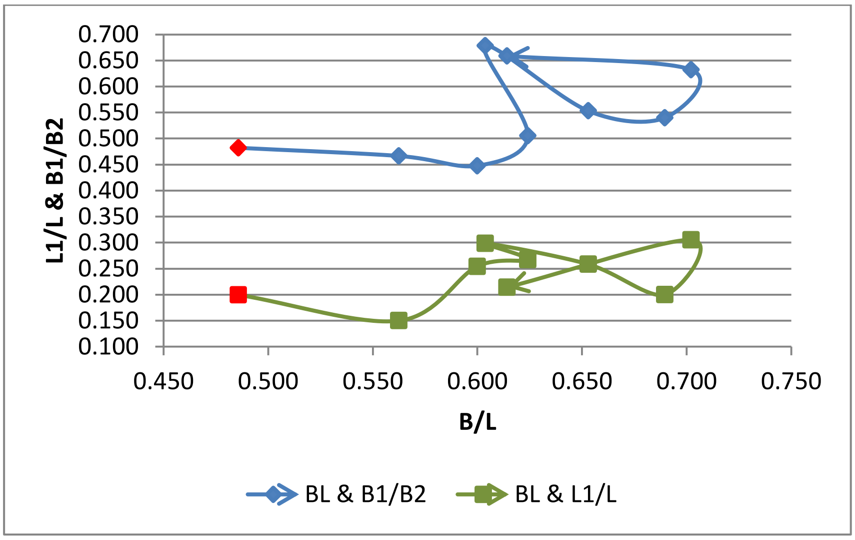


Figure 6.11b. TC2 chosen pointed handaxes by knapping generation.

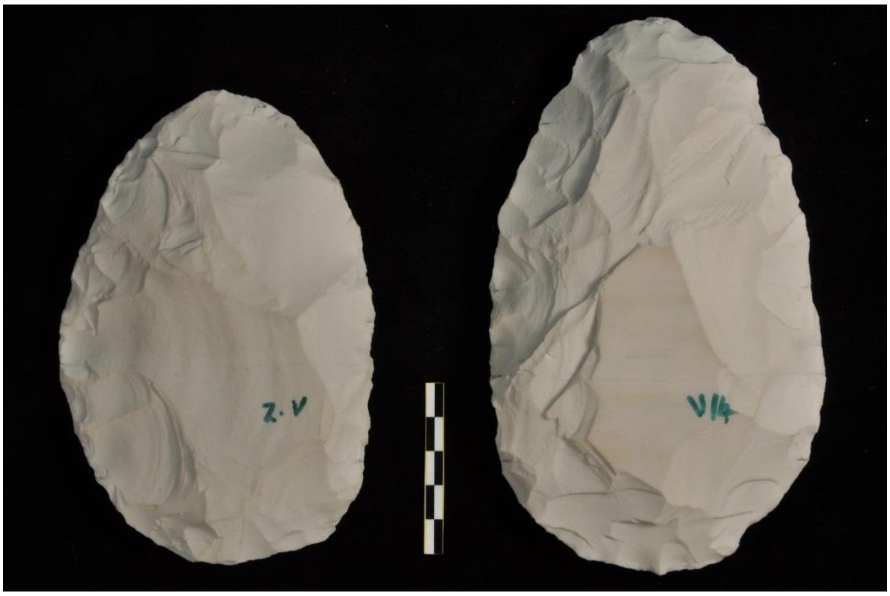


Figure 6.12a. The ovate handaxe TC1, showing the first and last copies in the chain, labelled 2V and V14 respectively.
Photograph: S. Page

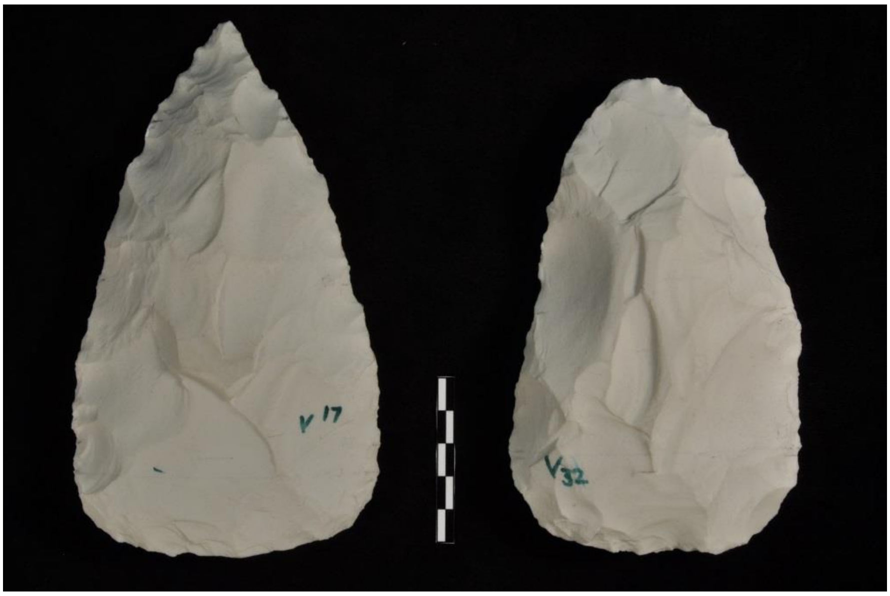


Figure 6.12b. The pointed handaxe TC2, showing the first and last copies in the chain, labelled V17 and V32 respectively.
Photograph: S. Page

6.5 Discussion

The difficulty of accurately reproducing multi-dimensional handaxe forms over extended generations of transmission was ably demonstrated by both TC1 and TC2. The dispersed nature of the refinement measure $\frac{T1}{L}$ in TC2 (Figure 6.5 & 6.7b) indicated that in this scenario of uninstructed end-state copying, inability to reproduce and transmit handaxe thickness at the tip (T1) and also as an overall measure ($\frac{Th}{B}$), on a consistent basis, as shown in Figure 6.7a & 6.7b, was likely the result of insufficient knapping skill. In both TCs, insufficient skill was also likely the primary reason why, on an intergenerational basis, the knappers struggled to maintain shape, as represented by upward and downward $\frac{B}{L}$ trends for TC2 and TC1 respectively (Figure 6.9).

The differing patterns of achievement (or non-achievement) present in the data suggest that the knappers of each TC regarded different attributes, or attribute combinations, as more or less essential or achievable than each other. In an attempt to establish an idea about the relative hierarchical importance of refinement and shape in TC2, Table 6.2 looked at the achievement of certain target form attributes, in relation to what was actually chosen to pass on as the target form for the next generation. Here, $\frac{B}{L}$ was selected as the key planform shape ratio, and $\frac{Th}{B}$ the key refinement ratio. Before the analysis took place, K3 and K4 were excluded because in each of those generations, one of the preform cores broke whilst being knapped so a choice was not involved in selecting which handaxe to pass through the TC: it had to be the one knapped from the remaining preform core. For the remaining generations, the closest shape ratio to that of the target form, for each generation, was selected as the chosen form on 4 out of 6 occasions, or 66.67% of the time, compared to 2 out of 6 occasions, or 33.33% of the time for refinement. In terms of sample size (*n* = 12), these numbers were too small to run a *Chi* squared test on, to enable significant interpretations to be made, but they were able to provide a tentative indication that for the pointed handaxes of TC2, there was a more consistent reproduction of planform shape, than refinement. In terms of selection, when both attributes were not the closest to the target form, $\frac{B}{L}$ was chosen as the primary characteristic on two occasions or 33.33% of the time (over zero for $\frac{Th}{B}$), indicating that planform shape was also perceived as more important than refinement, as a trait to pass on to the next generation.

TC2 Knapper	Chosen	B/L	Closest	Th/B	Closest
Base Trgt	Base Trgt	0.486		0.306	
K1	1	0.563	y	0.322	y
K1	0	0.627		0.354	
K2	0	0.676		0.310	
K2	1	0.600	y	0.303	n
K5	0	0.593		0.281	
K5	1	0.653	n	0.302	n
K6	0	0.616		0.377	
K6	1	0.690	n	0.220	n
K7	1	0.702	y	0.304	y
K7	0	0.754		0.326	
K8	0	0.653		0.255	
K8	1	0.614	y	0.360	n

Table 6.2. Analysis attempting to determine shape or refinement preference, when selecting the chosen form to pass through TC2.

Despite the putative preference for shape over refinement, within the shape metrics, for both ovates and pointed handaxes, the $\frac{B}{L}$ relationship proved difficult to manage, with the ovates becoming relatively narrower and longer, the points wider and shorter, and more cordiform. Due to the size of each respective change in form, it is more likely linked to skill than purely drift as a function of perceptual limitation alone. It can also be explained by considering the interdependent nature of all shape ratios in combination, especially when skill levels were relatively low. For TC2, $\frac{L1}{L}$ (excepting iteration 1), was always greater than that of the base target form, suggesting that keeping L1 at 20% from the butt (i.e. the same location as B2, in a pointed handaxe), was difficult and again, at this stage of the analysis, likely related to skill and transmission bias.

Independent of the other ratios, managing $\frac{L1}{L}$ (where the maximum width of the handaxe is located, in relation to length), is integral to maintaining basic handaxe shape – whether ovate or pointed. This is fundamental and was why $\frac{L1}{L}$ was the ratio used by Roe for classifying an assemblage as pointed or ovate. However, what was being illustrated by the generations of TC1 and TC2 is that when subject to the unrestrained and uninstructed nature of end-state copying, over multiple generations of copying, form started to lose the extremes that originally defined it. In both transmission chains, the result of cumulative variation was to create handaxes that were typologically closer to the cordiform bifaces defined by Bordes (1961b: 59) and Debénath & Dibble (1994: 136-137), positioning their shape between the extremes of the ovate and pointed handaxes, that were the original base target forms for TC1 and TC2 respectively. Figure 6.13 takes the significant trend for TC2 points to become more cordiform as a result of skill and TC bias, and charts the cumulative and convergent nature of that variation by presenting it with the $\frac{B1}{B2}$ and $\frac{L1}{L}$ ratios of all the chosen forms (tested but not significant), on an inter-generation basis, for TC1 and TC2. For pointed handaxes only, the result of the significant rise in $\frac{B1}{B2}$ would eventually lead to a less tapered and more cordiform handaxe. This trend represented a one-way convergence of form, from pointed handaxes only, to meet the $\frac{B1}{B2}$ ratio of the ovates. By doing so, it illustrated that when skill levels were relatively low and therefore variable, how an unfettered form of cultural evolution such as uninstructed end-state copying, could produce levels of variation resulting in a rapid typological change from point, to less tapered cordiform.

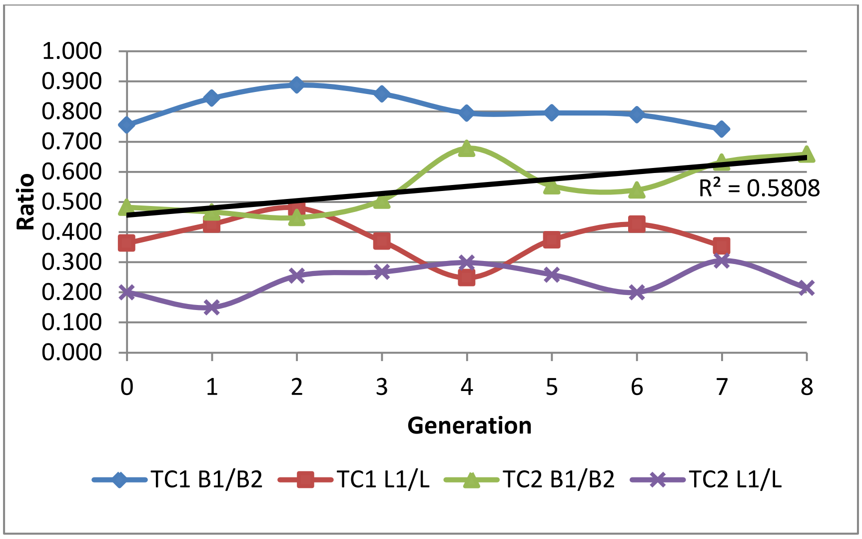


Figure 6.13. Tracking shape variation in chosen target form, by knapping generation, for TC1 and TC2. The use of R^2 shows moderate strength of relationship between the increase of $\frac{B1}{B2}$ (p = 0.017) and the cumulative knapping generations of TC2, leading to convergence of form from a pointed, to more cordiform handaxe shape.

6.6 Conclusion on Roe's measurement system

The cumulative result of the form changes demonstrated by each transmission chain is captured reasonably effectively by the Roe measurement system and its resultant ratios. However, the weakness in the system lies in the $\frac{B1}{B2}$ and $\frac{L1}{L}$ ratio values, the latter of which was specifically used by Roe to define pointed and ovate handaxes (0.00 – 0.350 defined a pointed handaxe and 0.351 – 0.550 defined an ovate). In the context of Experiment 2, the $\frac{B1}{B2}$ and $\frac{L1}{L}$ ratios for TC1's ovate base target form were 0.755 and 0.363, and for the 7th iteration of that TC they were 0.742 and 0.354 respectively. Both the target form and 7th iteration values are very close but when comparing the actual forms (Figure 6.12a and Appendix 4), as already noted, there was marked difference, with the 7th iteration also being typologically more of a cordiform than an ovate. This illustrates two factors, firstly: this overly etic procedure, where artefact form was judged by the analyst according to what they believed was the desired form in the mind of the original maker, provided a false classification of handaxe type, and secondly, in isolation, Roe's typology and its culture evolutionary agenda had the effect of falsely polarising handaxe shape by subsuming variation into two extreme forms, based on a limited use of metric data and ratio analysis.

6.7 Developing new metrics to improve Roe's measurement system

As noted in section 6.6 above, the way in which Roe used the metric data he collected, in some cases, did not adequately reflect variation in the handaxe's physical shape. This was likely a function of the ratios themselves, produced by using only two measurements and not taking account of other dimensions. The attendant effect of this approach was to reduce the individual characteristics of a three dimensional object to a ratio, each component of which was derived from the distance between only two points, taken from a single linear dimension. The closest Roe's system came to providing an indication of form change in 3 dimensions, was by using weight as a measure of handaxe mass.

The indication of TC1 form not changing, provided by the lack of significant trend data from the basic dimensional measures shown in Figure 6.2 and the ratio data presented in Figure 6.14, is shown to be unrepresentative of what was happening to handaxe mass, which varied substantially on an iterational basis. Although not a significant trend ($R^2 = 0.29$, $p = 0.16$), there was an increase in mass (Figure 6.14) not represented or explained effectively by the basic metrics or ratio data. However, even with changes in weight, gauging the effect of this variation on form was still problematic.

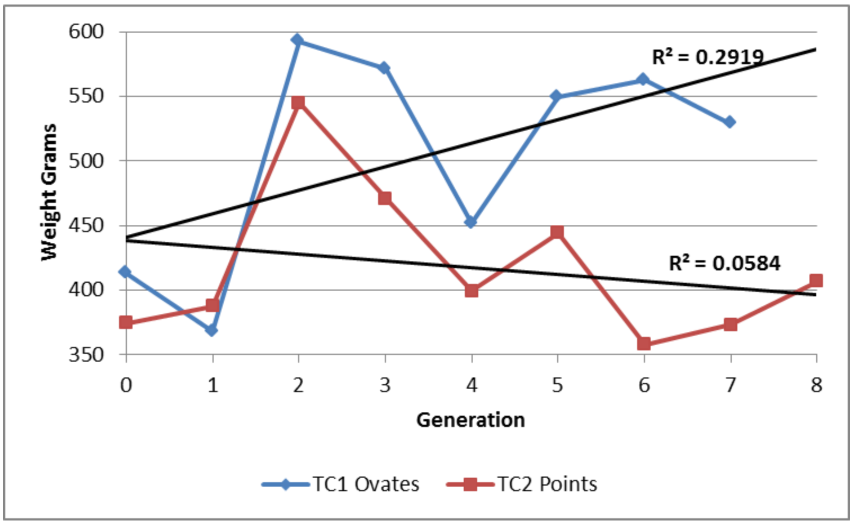


Figure 6.14. Weight of chosen forms for TC1 ovates (p = 0.16) and TC2 points (p = 0.53).

As a way of combating this inability to capture form change but still using metric analysis based on the existing Roe measurement points, further analysis was conducted (see section 3.5.6 for procedural details). The focus was on refining how the degree of handaxe shape or taper was viewed and reported, firstly relative to its length and secondly, as a measure of three dimensional shape, to calculate a single combined measure of Euclidean distance that could be used to chart movement away from (or towards) the shape of the base target form, more accurately than the $\frac{B1}{B2}$ and $\frac{L1}{L}$ ratios of Roe. For the ovates of TC1, when comparing the differences in shape between the base target form and iteration 7, as presented by the taper measure shown in Figure 6.15 (which takes account of handaxe length), compared with $\frac{B1}{B2}$ (which does not account for length) or $\frac{L1}{L}$, the degree of difference is more reflective of the change in physical form. It can now be seen that the change in taper for iteration 7 is 9.5% of the target form value, compared to 1.7% for the same $\frac{B1}{B2}$ change (Figure 6.10). Combine this with the radical shift in Euclidean distance of 17.234mm away from the base target form (Figure 6.15), and a truer representation of the actual planform shape change shown between the target form and iteration 7 (Figure 6.12a) is achieved.

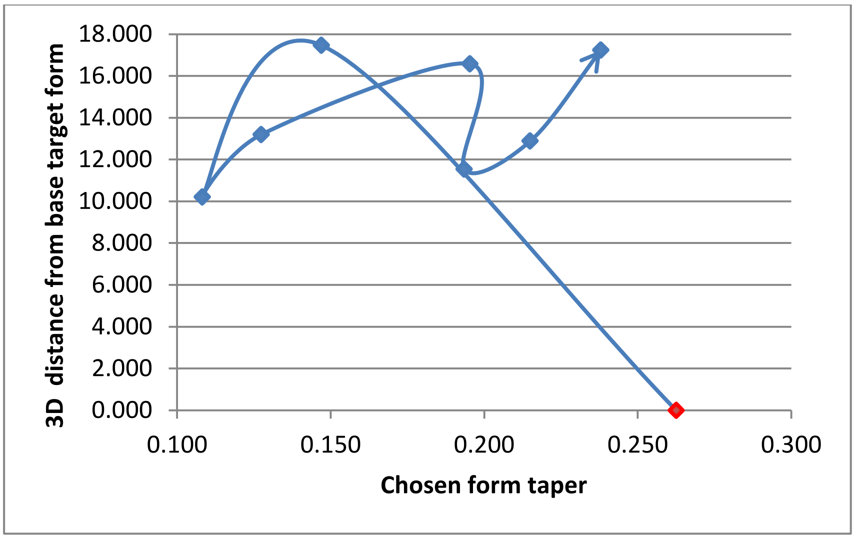


Figure 6.15. TC1 chosen ovates, showing Euclidean 3D distance from base target form and degree of taper for each chosen target form, by generation.

When taking the same approach to the pointed handaxes of TC2, the Roe measures appear to provide a better indication of how form was changing (compared to TC1); Figure 6.9 demonstrates that the pointed handaxes were becoming shorter i.e. wider relative to length (from the increasing $\frac{B}{L}$ value) and also less pointed as B1 expanded relative to B2 and also as L1 moved up a handaxe that was becoming shorter (Figure 6.11b). Despite this overall trajectory, for the eighth iteration, the $\frac{L1}{L}$ ratio of 0.214 was very close to the 0.2 of the base target form, again, a difference not reflected by the physical variation in handaxe shape. However, the combined Euclidean 3D distance of 35.369mm that iteration seven is from the base form (Figure 6.16a), provides a stronger indication of how different the two forms have actually become (also, see photographs in Figure 6.12b), a relationship not reflected so convincingly by Roe's measures alone. The strength of the relationship that each knapping generation was having on the change in Euclidean distance from the base target form was further demonstrated by Figure 6.16b, where R^2 = 0. 868 was accompanied by a *p-value* of 0.0002 indicating for this TC, Euclidean distance was an effective measure of highlighting knapper skill and its effect on a changing handaxe form.

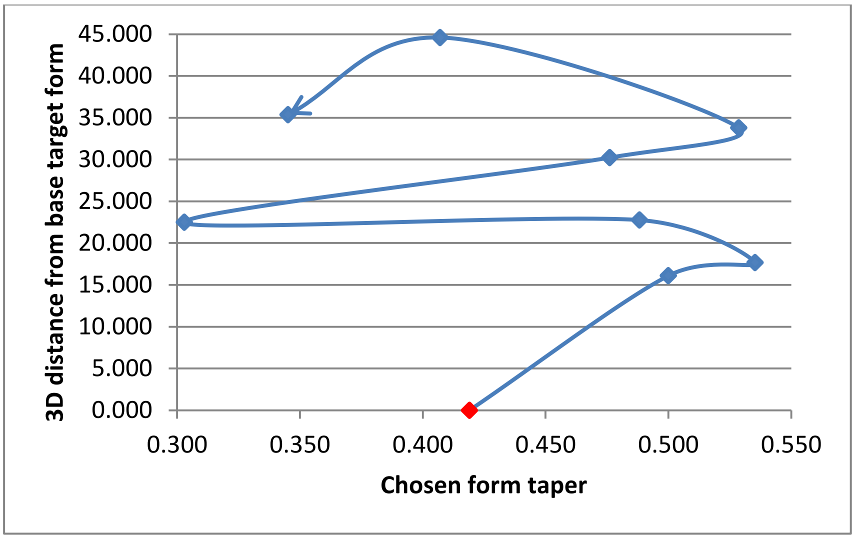


Figure 6.16a. TC2 chosen pointed handaxes, showing Euclidean 3D distance from base target form and degree of taper for each chosen form, by generation.

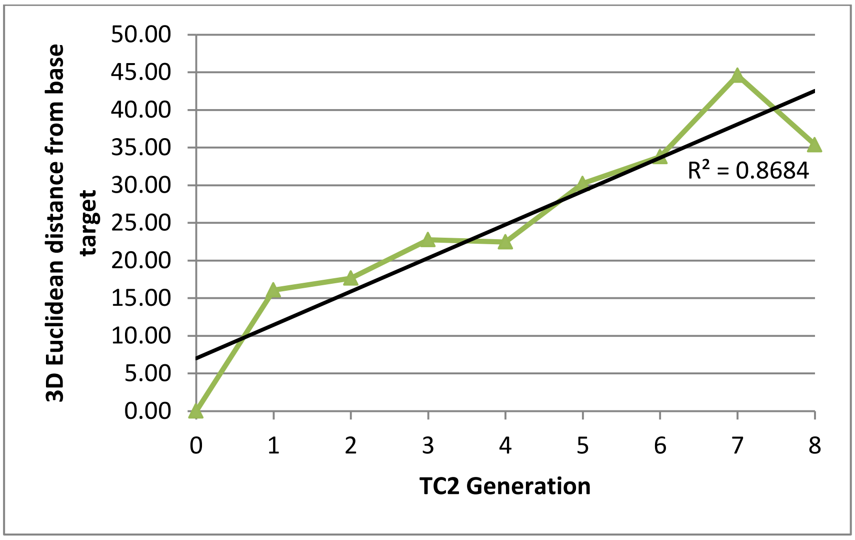


Figure 6.16b. TC2 chosen pointed handaxes. Euclidean 3D distance (mm) from base target form, by knapping generation. R^2 indicated a strong relationship between knapping generation and changing handaxe size (p = 0.0002).

6.8 Metric summary

Metric analysis of both transmission chains of Experiment 2 has shown that over relatively few generations of cultural transmission, uninstructed end-state copying, subject to limited skill levels, was a significant factor in accounting for variation and form change. In each instance, the objective was to reproduce a specific handaxe form and in each TC respectively, the result produced variation that was traditionally accounted for by the effects of raw material or reduction, both factors controlled for as part of the Experiment 2 methodology.

Over relatively few generations of transmission, ovates did not become pointed or vice-versa (as hypothesised) but there was a significant variation as both forms tended to lose the extreme attributes that defined their original Roe type (see Appendix 4). The handaxes of TC2 became more cordiform in nature and although the distinct shape of the base target form in each TC was still recognisable, there was an element of the two initially separate forms converging on one another. Figure 6.13 illustrated that this change, for the pointed handaxes of TC2 where $\frac{B1}{B2}$ was rising, (creating a more cordiform shape), was a statistically significant trend with the R^2 value interpreted as meaning that skill, or relative lack of, was likely responsible for that movement. Despite this situation, planform handaxe shape was still selected as a more important criterion, or survived more strongly, at the expense of refinement (Table 6.2).

It is likely that variable skill levels, operating within a fluid transmission system (uninstructed end-state copying), were the likely causes of form change, in shape and size, on both an intra-assemblage and inter-generational basis. Levels of change were much larger than would be expected if perceptual limitation was the sole generator of difference in form, and traditionally mooted causes of variation such as raw material had also been controlled for as much as possible (the aim in all the Acheulean experiments). In this context, the emergence of an almost neutral, more uniform cordiform handaxe could be described as a default handaxe shape, when no selective pressure was brought to bear. Exploration of variation not captured by analysis of Roe-influenced metric systems is addressed in the following sections.

6.9 Using planform and cross-sectional edge area (cm^2) measures as an improvement to Roe's system of metric points

Continued examination of the hypothesis that the Roe system (in isolation) fails to capture variation in the most effective manner, due to its reliance on a linear measurement between two points along axes that vary throughout the entirety of their length, can be further supported by using area based measures. Such measures were derived by using ImageJ measurement software, as highlighted and explained in section 3.5.8.

6.9.1 Handaxe refinement measures

In the first instance, in terms of handaxe refinement, the idea of having a complete measure for planform and edge areas (in cm^2) should allow for a fuller exploration of knapping skill applied to the whole handaxe (as opposed to using two metrics derived solely from its thickest point and thickness at *T1*). However, as determined after analysis of the entire handaxe assemblage, it was decided that the average edge area measure (*AEA*) derived from the digital imaging protocol did not provide an accurate measure of comparison, so Roe's original *Th* measure was used instead (see Methods section 3.5.8.2 for details). On that basis, for each generation, Figures 6.17 and 6.18 show a comparison of Roe's $\frac{Th}{B}$ ratio with that derived from each handaxe's thickness measure (*Th*), divided by the square root of its total planform area (*ADVA)*. For each iteration, in both TC1 and TC2, the $\frac{Th}{\sqrt{ADVA}}$ ratio was lower than the $\frac{Th}{B}$ equivalent meaning the handaxes were recorded as flatter and thus more refined than previously thought. This is because *ADVA* measured the planform size of the entire handaxe, as opposed to using solely its widest point as a ratio component. The square route of that measure was taken (for compatibility with *Th*), to provide a more representative measure. On this basis, $\frac{Th}{\sqrt{ADVA}}$ likely provided a more complete measure of refinement and knapping skill because one of its components derived, perhaps more meaningfully, from dimensions of the whole handaxe. On an iterative basis $\frac{Th}{\sqrt{ADVA}}$ still indicated changes, supporting the idea that the knapping dynamic between thickness and planform area was not a relationship easily maintained, especially when subject to uninstructed end-state copying, in an environment of relatively low skill levels.

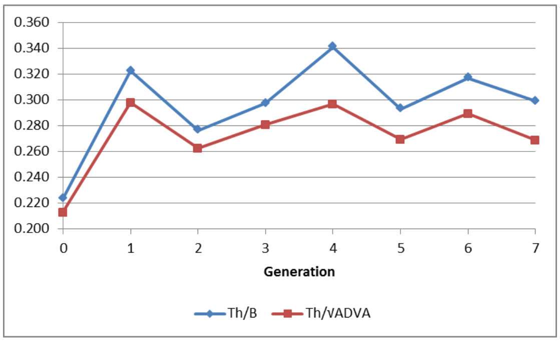


Figure 6.17. TC1 ovates: comparison of $\frac{Th}{\sqrt{ADVA}}$ ratio with Roe's $\frac{Th}{B}$ ratio, on a generational basis.

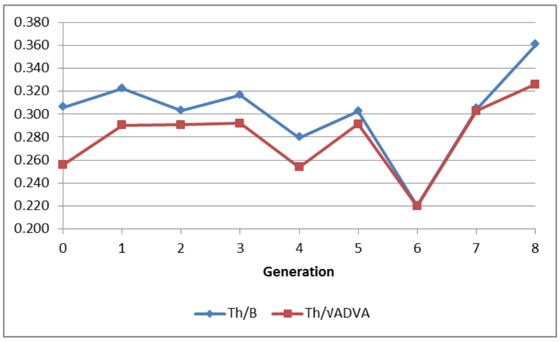


Figure 6.18. TC2 points: comparison of $\frac{Th}{\sqrt{ADVA}}$ ratio with Roe's $\frac{Th}{B}$ ratio, on a generational basis.

As a further addition to the measures of handaxe refinement explored by Roe, ImageJ was also used to calculate the area of remaining cortex on both dorsal and ventral faces, as the target forms passed through each of the transmission chains. Refinement and the process of handaxe thinning focused on the effective reduction of edge area (Bradley & Sampson, 1986; Stout, 2011; Stout *et al*, 2014), as was the case in each of the base target forms, also required that flaking was invasive enough to remove the majority of surface cortex. On this basis, if transmission of the two traits was linked, a low $\frac{Th}{\sqrt{ADVA}}$ ratio should be accompanied by low levels of residual cortex. To enable such comparison, all ratios were converted to percentages and remaining cortex area, both ventral and dorsal, was plotted as a percentage of the total area of each respective handaxe face, for each iteration of both transmission chains. For both the ovates of TC1 (Figure 6.19) and the points of TC2 (Figure 6.20), average ventral cortex percentages of 14.00% and 5.55% respectively, were lower than their dorsal counterparts of 46.69% and 43.16% respectively. This indicated that in the process of bifacial knapping, the participants found ventral face management easier (perhaps due to its flatter surface, compared to the dorsal face) or regarded it as more important, with the result that it became a more accurately transmitted trait. This was particularly relevant for the pointed handaxes, where ventral cortex remained consistently low on an iterative basis, varying at relatively minor levels of between 1% and 11% (with the exception of knapper 2 in the TC) and always below the refinement level measured by $\frac{Th}{\sqrt{ADVA}}$. However, the high levels of vestigial dorsal cortex for both TCs moved consistently above the levels of refinement measured by $\frac{Th}{\sqrt{ADVA}}$ and all other measures (excepting one iteration in each TC), indicating that the dorsal face was less knapped than the ventral face. Although both faces were a different shape (ventral face flat and dorsal face convex), they both required knapping and especially thinning, to replicate the morphology and residual cortex levels of the target form. In this respect, the lower levels of attention received by the dorsal face indicated it was regarded as hierarchically inferior to the ventral face, either deliberately or through lack of skill – a conclusion which cannot be made by looking at Roe refinement measures alone. As $\frac{T1}{L}$ measured thickness of tip (Roe used it as an additional refinement measure but only for pointed handaxes, not ovates), it is likely that a low $\frac{T1}{L}$ rating would be the result of effective invasive flaking, therefore contributing to low percentage levels of vestigial cortex. However, although dorsal cortex was kept low/comparative to that of the TC2 base target form for one generation, from the second generation on, cortex increased from almost zero to over 40% for the rest of the transmission chain (Figure 6.20). In the context of handaxe refinement, these results indicate that both the $\frac{Th}{B}$ and $\frac{T1}{L}$ measures of Roe do seem relatively blunt tools that miss much of what characterises the chief components of achieving refinement, namely knapping skill or the ability to manage and control for multiple attributes simultaneously. This is particularly true when comparing the generational differences that affect the trajectory of artefact form and characteristics, as it was copied and passed through multiple generations of knappers.

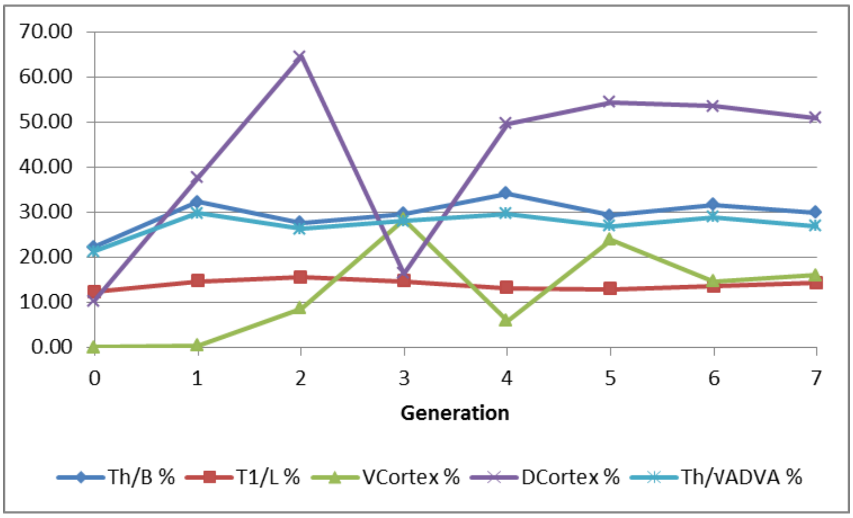


Figure 6.19. Refinement measures for TC1 ovates with the addition of residual cortex areas on both dorsal and ventral faces, presented as a percentage of each face's total area.

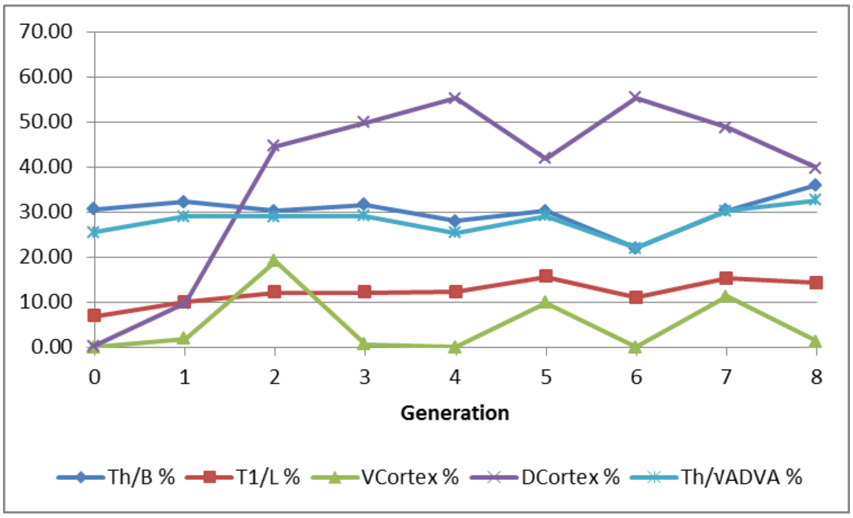


Figure 6.20. Refinement measures for TC2 points, with the addition of residual cortex areas on both dorsal and ventral faces, presented as a percentage of each face's total area. Ventral cortex was managed well, in contrast to all other measures.

6.9.2 Handaxe shape measures

The addition of area based measures to quantifying changes in handaxe form may represent a technological advance but in isolation, a measure like $\frac{Th}{\sqrt{ADVA}}$ still fails to offer an effective picture of handaxe trajectory as a result of intergenerational change. To solve this problem requires the bringing together of measures of area with measures of actual shape change, such as percentage iterative change in handaxe area, degree of taper and 3D Euclidean distance, as explored in section 6.7 and combined in Table 6.3 (below). In this section, the original Roe measure of $\frac{B}{L}$ for size and shape is used for comparison, and $\frac{L1}{L}$ has also been added to provide an indication of where the widest point of the handaxe is located, which is a vital aid to view alongside area and total Euclidean distance from the target form. This provides a real indication of where shape change is actually occurring and in this respect, $\frac{L1}{L}$ is perhaps the most useful of all the Roe measures.

Generation	ADVA	% i change	Taper %	3D distance (cm)	L1/L %	B/L%
TC1 Tgt	116.93	0.00	26.26	0.00	36.30	70.55
1	94.86	-18.88	14.71	17.46	42.65	66.18
2	122.26	28.89	10.82	10.20	48.05	68.18
3	114.38	-6.45	12.74	13.19	36.94	64.33
4	102.31	-10.55	19.54	16.58	24.83	60.69
5	116.09	13.47	19.35	11.53	37.42	63.87
6	122.47	5.49	21.51	12.88	42.58	65.16
7	116.55	-4.83	23.81	17.23	35.40	60.25
TC2 Tgt	103.34	0.00	41.90	0.00	20.00	48.57
1	99.74	-3.48	50.00	16.09	15.00	56.25
2	106.55	6.83	53.54	17.66	25.45	60.00
3	112.69	5.76	48.83	22.76	26.75	62.42
4	104.93	-6.88	30.30	22.47	29.87	60.39
5	99.13	-5.53	47.62	30.23	25.85	65.31
6	100.70	1.58	52.87	33.78	20.00	68.97
7	85.53	-17.49	40.71	44.60	30.53	70.23
8	90.46	5.77	34.52	35.37	21.43	61.43

Table 6.3. Shape measures of handaxe form for TC1 and TC2. Handaxe area in cm^2 is derived from an average of dorsal and ventral faces. The % iterative (i) change then provides an indication of size change to be interpreted in combination with taper and Euclidean 3D distance from the base target form.

If Roe's $\frac{B}{L}$ ratio is viewed without reference to any of the new measures, it gives the impression that shape and size are varying at low levels of change, especially for the ovates of TC1 where variation was between 70.55% and 60.25%. That translates to a cumulative change of 10.3% over 7 generations

(Table 6.3), or a mean of 1.47% per generation. This is clearly not revealing how form was evolving through each of the respective transmission chains. As an initial measure of overall shape, in both TCs the single largest shift in 3D Euclidean distance happened in the first generation of copying, from the zero start of the base target form to 17.46mm and 16.09mm for TC1 and TC2 respectively (Table 6.3). From the second generation on, for the ovates of TC1, distance from the base target remained between 10.20mm and 17.23mm, however, for the points of TC2 it rose consistently for each iteration with the exception of iteration 8, the last generation in the TC (Table 6.3). This indicates that for both chains, in terms of end-state copying , variation was not within low boundaries (as suggested by $\frac{B}{L}$); a fact backed up by the change in average planform area (*ADVA*), where extreme iterational changes could be seen (Figures 6.21 and 6.22), especially for the ovates where area changed from -18.88% to + 28.89% in a single generation (Table 6.3); a change barely registered by $\frac{B}{L}$. Such levels of variation indicate that skill levels were not at an advanced enough level to maintain the overall planform proportions of the base target form, further suggesting that a measure encompassing aspects of handaxe size is needed to realise levels of iterational change more effectively.

Using the taper percentage provides an indication of how shape changes within the area fluctuations discussed above. In both TCs and especially, as would be expected for the pointed handaxes (Fig 6.21), taper, an integral part of the pointed form provides one of the more sensitive measures. The $\frac{L1}{L}$ trajectory in both TCs mirrors that of the taper line and as mentioned above, indicates that $\frac{L1}{L}$ is the most effective of the Roe measures for indicating how form was actually changing. In TC1, handaxes became less tapered (Fig 6.21) and more ovate, as the degree of taper failed to reach the 26.26% of the base target form, for the entire duration of the TC (Table 6.3). $\frac{L1}{L}$ then shows that the widest point of the handaxe was moving up its length axis towards the centre of the piece, to its most extreme point, in Generation 2, where the widest point of the handaxe, at 48.05%, was almost at the very centre of the piece (Table 6.3). In this context, the knappers struggled to manage the horizontal axis of the handaxe (i.e. where its widest point should be), which is essentially what defines its shape and typology, especially in TC1, where $\frac{L1}{L}$ trajectory changed direction every two generations. In TC2 (with the exception of 3 iterations: 4, 7 & 8), handaxes became more tapered than the 41.9% of the base target form (Table 6.3). This was effectively a result of the knappers failure to control handaxe proportions at *B1* and *B2* (adjusted for length), and match the shape of their specific target form. The manner in which this process affected the form of the pointed handaxes is again best illustrated by $\frac{L1}{L}$, showing that as they became more tapered, the widest part of the handaxe (L1) moved predominantly up the length axis. The result of this, combined with the Euclidean trend (Figure 6.16b) for 3D movement away from the base target form, meant that TC2 handaxes tended to become less pointed and more cordiform in nature, as they passed through the TC (Figure 6.22).

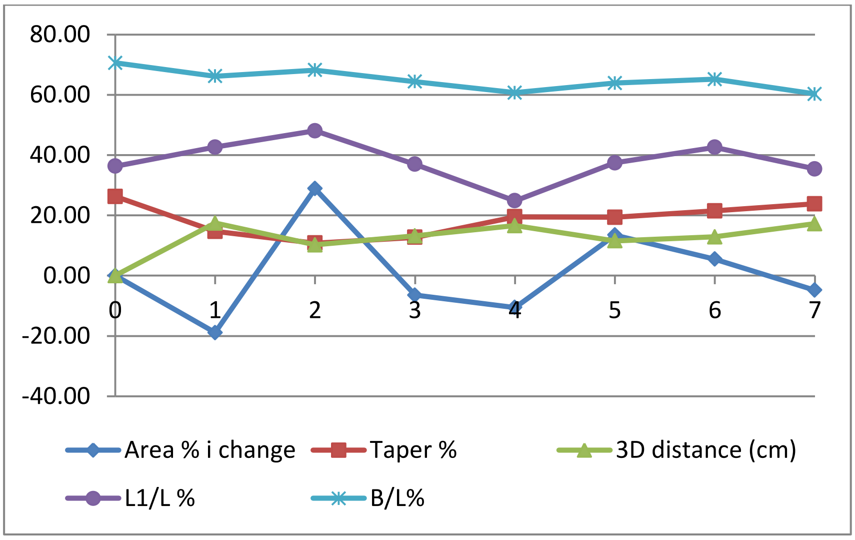


Figure 6.21. Iterative variation and trajectory of shape measures for TC1 ovates. Of note is the very stable picture presented by the $\frac{B}{L}$ measure of Roe, which hides significant variation in other shape related measures.

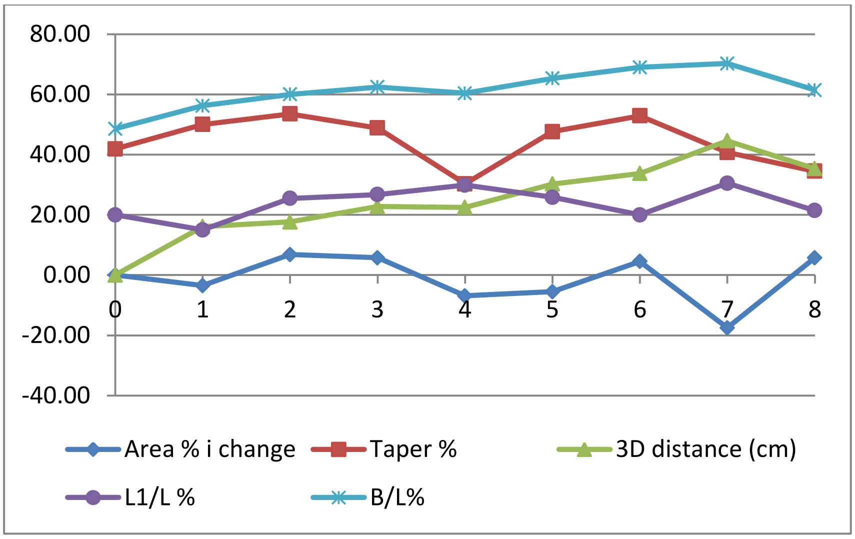


Figure 6.22. Iterative variation and trajectory of shape measures for TC2 pointed handaxes. Of note is the difficulty in managing the degree of taper present in the pointed handaxes, especially in relation to $\frac{L1}{L}$, Roe's most effective measure.

6.9.3 Conclusion

In the context of measuring intergenerational changes and the resultant trajectory of handaxe form as it passes through transmission chains, for both measures of refinement and shape, it can be seen that application of Roe's data points to new measures of taper and 3D Euclidean distance provided a more refined way of looking at aspects of variation and form change. The addition of these shape based calculations to new measures of planform and residual cortex areas provided a dimension not available using the Roe system alone. Such measures also permit a more refined way of assessing iterative changes not apparent from Roe ratios that have been constructed from single data points on axes that are fluid throughout the entire of their dimensions. For example, in this respect, using area measures of vestigial cortex, in combination with measures such as $\frac{T1}{L}$, could act as more effective measures of refinement, which may be transmitted independently or at the expense of other traits (section 6.9.1). The use of area-based measures such as *AVDA*, in combination with Roe shape measures, specifically $\frac{L1}{L}$, also allows for shape and refinement measures to be viewed together rather than in isolation (section 6.9.2); an important factor when considering that handaxe form evolved, when subject to multiple generations of copying in transmission chains, not because of single traits in isolation but because of interplay between multiple traits.

6.10 Handaxe symmetry

As discussed in section 3.5.9, the recognition and management of symmetry in lithic forms in the Acheulean, is regarded as requiring a cognitive grade shift from the level of understanding required to knap Oldowan or Mode I artefacts. Beyond that, it is also regarded as requiring a significant level of physical knapping skill (Stout, 2002b) to create handaxe forms where levels of asymmetry are maintained at a low level. Experiment 2 explored the trajectory and levels of ovate and pointed handaxe asymmetry as they passed through their respective transmission chains. Each handaxe selected as an inter-generational target form was photographed and assigned a Ventral (face) Asymmetry Index (*VAI*) by using Flip Test software (as described in section 3.5.9). Figure 6.23 plots each of the handaxe *VAI*s, by TC, against the scale of asymmetry advocated by Hardaker & Dunn (2005).

It was hypothesised that in line with the metric and area based measures of handaxe form, there would also be a marked deterioration in symmetry as the TCs progressed. This was not the case: the *VAIs* of between 1.5 and 3.0 or ‘very high’ levels of symmetry were achieved in nearly every knapping iteration (Figure 6.23). So, in overall terms, once the concept was understood, as it was by the contemporary cohort of experimental knappers, the low *VAI* scores indicated it was not difficult to maintain ‘very high’ levels of symmetry between each generation of copying, on a consistent basis.

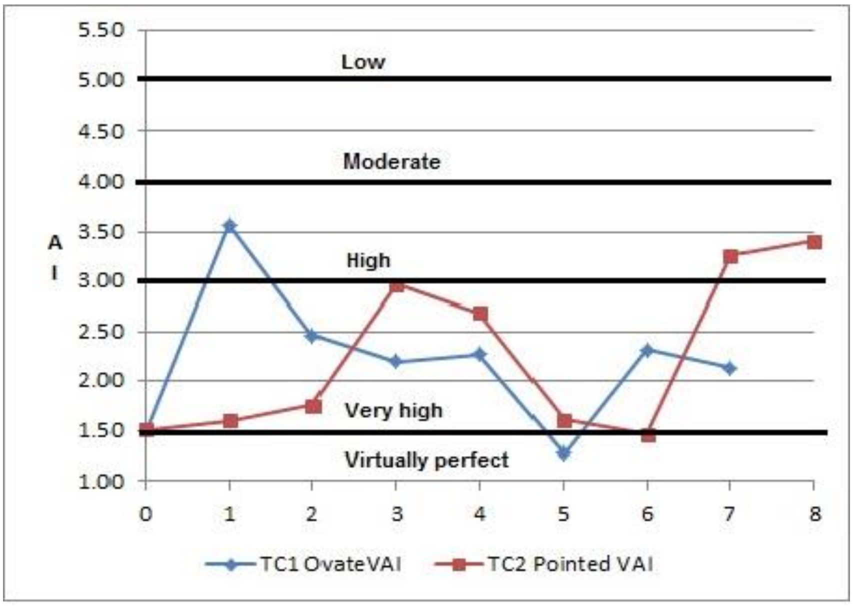


Figure 6.23. Ovate and pointed TC trajectories by knapping generation, showing an accurate transmission of symmetry at a ‘very high’ level.

To support the survival or accurate transmission of symmetry as a trait, when subject to conditions of uninstructed end-state copying, it was necessary to examine it in relation to the behaviour of other measures of shape and refinement, over multiple generations of copying. For handaxe size, the average area in cm² of the dorsal and ventral faces (*ADVA*) was plotted for both TCs against the *VAI* of each handaxe (Figures 6.24 & 6.25). The scatters demonstrate that whilst the level of symmetry was maintained at a ‘very high’ level, handaxe size varied extensively between 94.86cm² and 122.47cm² in TC1 and 85.53cm² and 112.69cm² in TC2, around the area of the original target form (highlighted in red) in both TCs. Extending that measure of size to one of refinement, the next stage was an examination of the *VAI*s in conjunction with $\frac{Th}{\sqrt{ADVA}}$. For the ovates of TC1 (Figure 6.26), all handaxes were thicker relative to their size when compared to the target form ratio of 0.213, reaching an extreme of 0.298. For the pointed handaxes of TC2 (Figure 6.27), where the base target form ratio was 0.256, variation was spread between 0.220 and 0.326. In both cases, although the *VAI* had been kept low, resulting in handaxes evolving with ‘very high’ levels of symmetry, size and refinement had fluctuated widely.

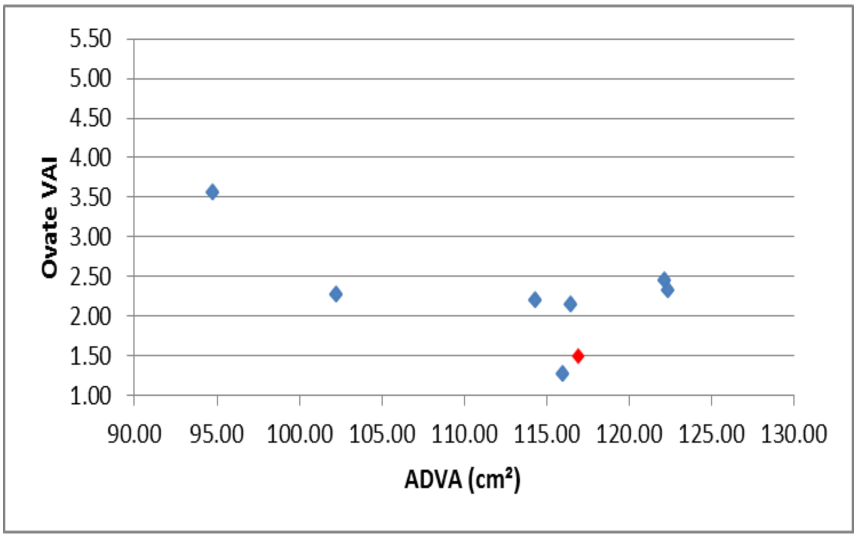


Figure 6.24. TC1 *ADVA* & Ovate *VAI.* High levels of *ADVA* size variation but symmetry survived.

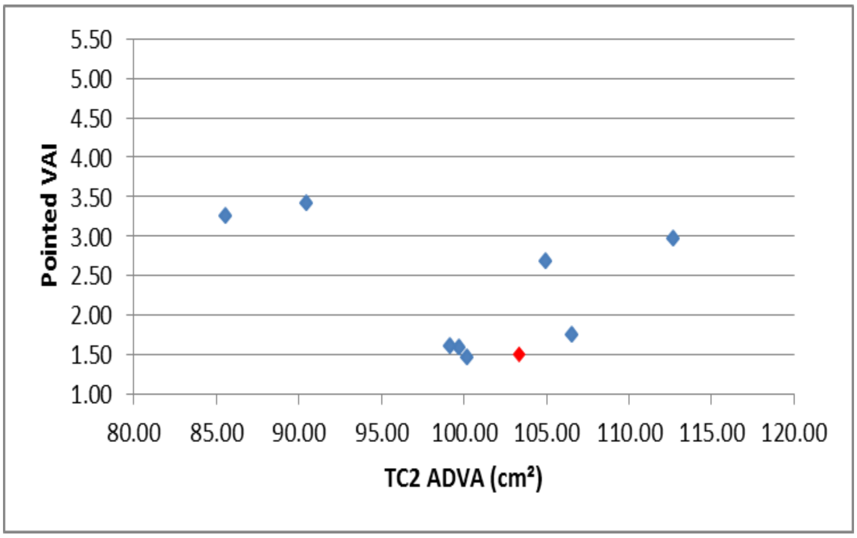


Figure 6.25. TC2 *ADVA* & Pointed *VAI*. Again, *ADVA* fluctuated widely whilst ‘high’ levels of symmetry were maintained.

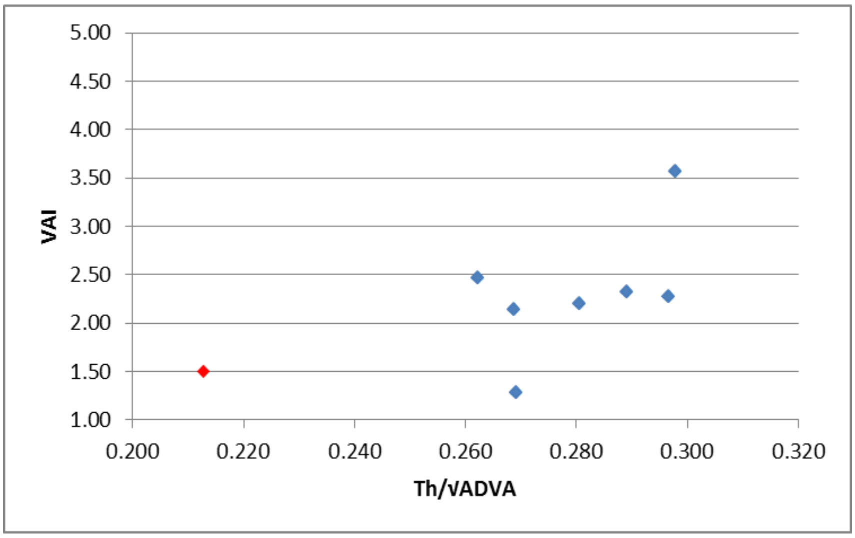


Figure 6.26. TC1 Ovate $\frac{Th}{\sqrt{ADVA}}$ and *VAI* illustrating that symmetry was easier to maintain and transmit than refinement, as $\frac{Th}{\sqrt{ADVA}}$ indicates thicker handaxes relative to planform area.

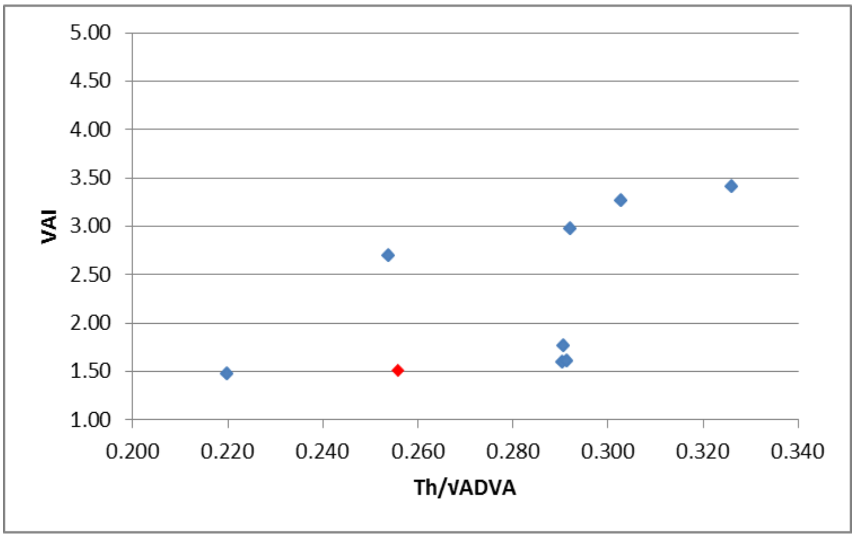


Figure 6.27. $\frac{Th}{\sqrt{ADVA}}$ and *VAI for the pointed handaxes of TC2*. A better performance than for the ovates of TC1, but as a trait, $\frac{Th}{\sqrt{ADVA}}$ was still harder to replicate and transmit than *VAI*.

With regard to handaxe shape, Roe's effective $\frac{L1}{L}$ ratio was converted to a percentage and also plotted against the *VAI* for each handaxe. Both Figure 6.28 and 6.29 show an inability to manage the $\frac{L1}{L}$ relationship, where, as reported in sections 6.5 and 6.6, there was a trend for both handaxe forms to lose their defining ovate or pointed shape and become more cordiform in nature. This loss of shape, as with the loss of size and refinement measures reported above was not, however, accompanied by a loss in symmetry. This confirmed that although symmetry may be a defining factor of the Acheulean handaxe, once mastered, even when subject to the high levels of variation that were inherent with uninstructed end-state copying, it was a trait that survived in preference to, and at the expense of, other traits in the culture evolutionary process illustrated by TC1 and TC2.

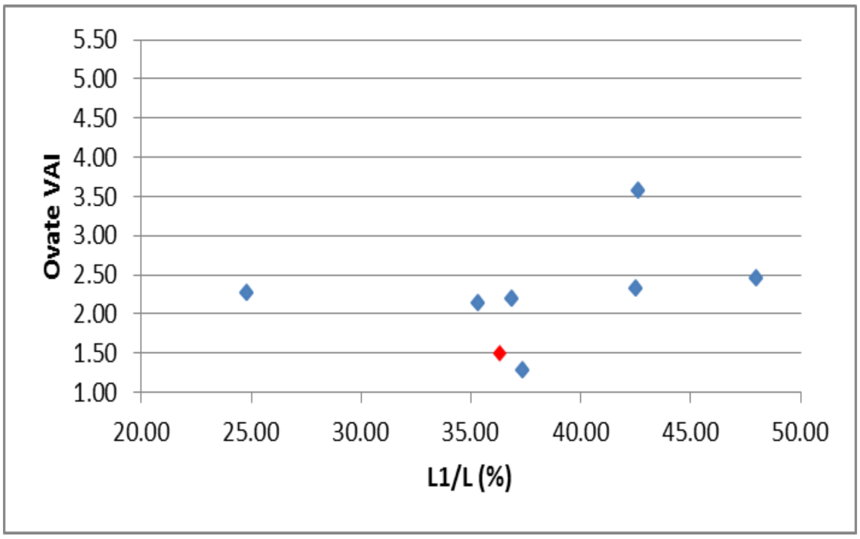


Figure 6.28 TC1 Ovate $\frac{L1}{L}$ & *VAI* showing a loss/variation in handaxe shape that is not accompanied by a loss in planform symmetry.

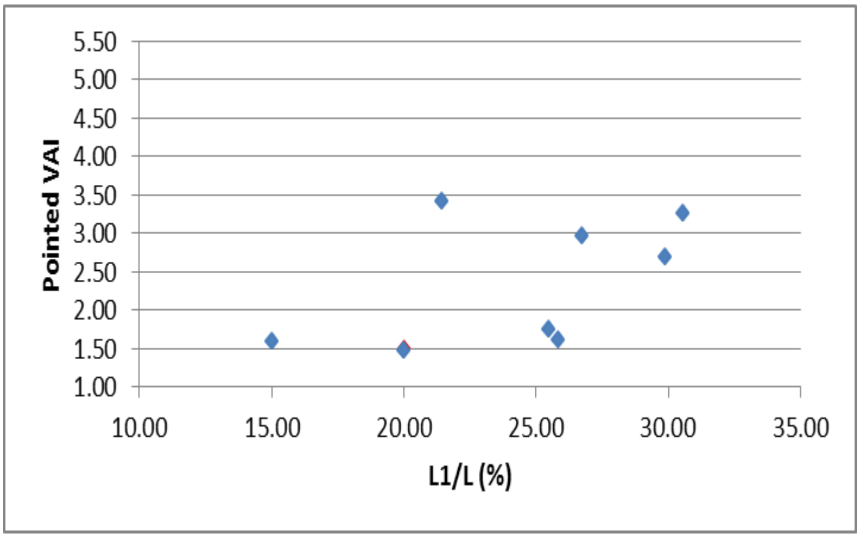


Figure 6.29 TC2 Pointed $\frac{L1}{L}$ & *VAI*. *L1* is prone to moving up the handaxe making it more cordiform in shape but levels of symmetry remain 'very high'.

6.11 Conclusion

In isolation, despite the ovate handaxes of TC1 and the pointed handaxes of TC2 behaving differently on an iterative basis, the Roe measures of refinement described in section 6.4 showed their ability to identify change in attribute form but only on a two-dimensional basis. As with the blades of Experiment 1 (Chapter 4) it was likely that handaxe form was changing because, when subject to uninstructed end-state copying, the knappers lacked the necessary levels of skill to manage multiple attributes on a simultaneous basis. The same could be said of Roe's shape measures, especially for the points of TC2. What Roe's metrics lacked was the ability to reflect *how* the change in ratio was affecting the overall form of the handaxe; this was illustrated by the closeness of ratios such as $\frac{L1}{L}$, which viewed in isolation, when compared to substantial form change indicated (in the same handaxe) by variation in Euclidean distance (section 6.7), is a shortfall in the system. The essence of this problem lies in two factors; firstly, using solely dimensional metrics presented a restricted way of viewing handaxe form, especially refinement. Secondly, by its focus on single point metrics, it ignored other measures particularly relevant to evaluating handaxe shape.

From the perspective of handaxe refinement, examining levels of residual cortex on both faces, presented an extended insight into how each knapper approached the problem of replicating form and also what they considered important in that process: for some knappers, levels of residual cortex were more a by-product of trying to achieve (and therefore transmit) a different attribute. $\frac{T1}{L}$ as a refinement measure could indicate a narrow tip relative to length, but that could have been achieved by working the ventral face more exclusively than the dorsal, therefore not providing a true measure of refinement and knapping ability and masking an element of form change that was impacting on the evolution of handaxe form.

From the perspective of handaxe shape, single point metrics such as length, width, or $\frac{B}{L}$ (as a ratio) are unable to capture the loss (or gain) experienced in handaxe size more effectively represented by the area based measures produced by ImageJ. A further and perhaps more crucial drawback of the system was that $\frac{B1}{B2}$ did not capture aspects of symmetry which, in TC1 and TC2 (section 6.10), was revealed to be a dominant attribute in terms of the cultural transmission process. Handaxe symmetry, once mastered as a concept, was preserved and transmitted at a 'very high' level throughout both TCs. This is perhaps indicative of the long-term survival of the handaxe as a symmetrical tool form, throughout extended periods of the Palaeolithic. Even with increasing levels of $\frac{Th}{\sqrt{ADVA}}$ resulting in thicker handaxes and the loss of the defining extremities of the pointed handaxe caused by the failure of the knappers to manage and accurately transmit $\frac{L1}{L}$, resulting in the appearance of a more cordiform handaxe, planform symmetry was still preserved. To this end, in addition to the Roe metrics, the additional geometric, area based and symmetrical measures will be applied to all the remaining handaxe experiments in this programme, to produce a combined system that more accurately captures and attaches interpretative value to variation in handaxe form.

In the context of transmission bias, for the TCP of uninstructed end-state copying, levels of variation within the standardised tool form were higher than would be expected if perceptual limitation was the sole driver. This is likely reflective of the fact that none of the TC members were expert or master knappers with skill levels sufficient enough to accurately manage multiple attributes simultaneously. Without communication, on an intra or inter-generational basis, the overall handaxe norm that was defined by the base target form for each TC broke down quickly. Although pointed handaxes did not evolve into ovates, the fact that a default cordiform shaped handaxe developed in its place fulfilled the hypothesised outcome and was perhaps not surprising. What did seem counter intuitive however, was the survival and persistence of planform symmetry.

Chapter 7.

Experiment 3: the effects of one-to-one knapping instruction from a cultural parent, on copying pointed handaxes in a transmission chain

7.1 Introduction

Results obtained from the measurement procedures used in Experiment 2 (i.e. size, shape, refinement, 3D Euclidean distance, taper, handaxe area and residual cortex percentages, together with indexes of asymmetry), all indicated that levels of variation produced in transmission chains, when subject to uninstructed end-state copying, were responsible for erosion of established form over multiple generations of copying. This indicated a possible convergence of form along a continuum of variation, in an unregulated scenario of copying over multiple generations. This is a mechanism not necessarily apparent from an etic examination of the resultant handaxes without the prior knowledge that firstly, they were part of a TC and secondly, that the resultant handaxes were not deliberately made as different tool types but were, in fact, the result of knappers attempting to produce distinct ovate or pointed forms. If these circumstances were a replication of a process that happened in the Middle Pleistocene, the archaeological record could be representative of a convergence of form that was not consciously produced. The resultant small levels of variation within a standardised artefact like the handaxe, could have ultimately resulted in a stasis of form regulated purely by functional needs e.g. the maintenance of a thin and sharp cutting edge (Hayden & Villeneuve, 2009; Mitchell, 1996; Shea, 2007; Simão, 2002). Where this was potentially the case, transmission chain theory, as schematically highlighted in Figure 2.9, can help indicate transmission biases or external cultural factors that likely impacted upon the rate of evolution of artefact form. On that basis, Experiment 3 is designed to provide insight on the effect of cultural parenting, over multiple generations of copying the same base target form used in Experiment 2, TC2: the pointed handaxe.

7.2 Objectives

The uninstructed end-state copying of Experiment 2 represented a base-line model against which to compare different aspects of the culture evolutionary process. On that basis, the remaining experiments explored the effects of two distinct types of transmission bias on the multi-generational copying of Acheulean handaxe form. The objectives of Experiment 3 were:

- To explore how pointed handaxes evolved through the multiple generations of a transmission chain, subject to one-to-one expert instruction from a cultural parent.
- To evaluate how that transmission bias impacted on the forms of handaxe measurement, developed in Experiment 2, through the transmission chain of Experiment 3.

In the context of vertical transmission *(sensu-stricto*), passing on of instruction and knapping technique would occur from parent to offspring (Boyd & Richerson, 1985; Lycett & Gowlett, 2008). With regard to the experimental handaxe programme, this scenario was impossible to recreate and so required the use of a surrogate parent. All, excepting one of the knappers were of novice status when they began the programme and were taught by BB who, as a knapper and mentor, was revered and unquestioned by the novices, in the same fashion as biological parent would be by their offspring. In this context, 'cultural parent' is perhaps the closest replication of the original relationship that could be created. In the wider context of cultural transmission, this construct is distinguished from prestige bias, in that instruction is occurring and *savoir-faire* is being passed on, on a one-to-one basis; there is no subtext of imitating one group member in preference to another group member because of perceived or actual difference in status.

7.2.1 Target Form

A single target form was selected for this experiment and was used in a single transmission chain. The target form used was the same pointed handaxe as in TC2 of Experiment 2 (Figure 6.1b). The pointed handaxe (TC2) was chosen in preference to the ovate form (TC1) because the knappers of TC2 produced a greater range of variation in Euclidean distance, from the base target form, than did the TC1 knappers (Figure 6.15, 6.16a & 6.16b for significance). On this basis, because of the difficulty of managing the pointed form in a TCP governed by uninstructed end-state copying, it was felt it presented a better base-line model with which to compare the results of Experiments 3 and 4 (Chapter 9). The knapping task of controlling and reproducing a pointed form, in conjunction with managing L1, thickness and level of symmetry, was also regarded as providing a test less familiar to the knapping cohort than producing an ovate handaxe form.

7.3 Methodology

7.3.1 Transmission Chain Protocol

Each generation (n=7) of the Experiment 3 TC was comprised of two members: the cultural parent and the novice knapper. In each generation, the cultural parent remained the same, while the novice was replaced after each knapping session. As in Experiment 2, each knapper received two standardised, porcelain preform handaxe cores with the objective of producing copies of the target form they were presented with. They then chose which of their two handaxes most closely matched the form and attributes of their target form; that handaxe then became the target form for the next generation. This process was repeated for the duration of the TC. The cultural parent decided that in addition to general knapping instruction, he would focus specifically on biface thinning skills, which should have the effect of maintaining levels of overall handaxe refinement, whilst maintaining handaxe size. This area of focus was chosen as refinement experienced significant degradation in Experiment 2, as handaxes became both shorter and thicker, and smaller (in cm^2) and thicker respectively (Figure 6.6 and 6.27). During this process, the cultural parent was able to use verbal instruction, gesturing, pointing and the mimicking of actions deemed useful to aid the knapper produce a close match to their target form; actual knapping of the preform cores/blanks by the parent was not permissible. The novice was permitted to ask questions of the cultural parent and view and handle the target form throughout the duration of their knapping session. It was the novice who decided when to stop knapping each handaxe, based on reaching the point where they felt they could not achieve a closer match and further knapping would be detrimental to that objective.

As with Experiment 2, hammerstone selection was regarded as an integral part of knapping skill and the choice of which stones to choose from the available selection was the choice of each knapper. However, within that selection (Figure 7.1), the cultural parent could advise on the best hammerstone to use for a specific task or conversely the knapper could ask for advice, from the cultural parent, on which stone would be most appropriate for that task.

Figure 7.1. Hammerstone choice: knappers could choose which hammertones to use and when, from a different variety of weights, sizes and textures. Photograph: S. Page

7.3.2 Measurement

In the first instance, all Roe measurements were taken as described in section 3.5.5. This allowed for the creation of the standard Roe ratios and also acted as the basis for the taper and 3D Euclidean distance measures. As a baseline, they also allowed for comparison against the area based measures developed using ImageJ software (sections 3.5.7 – 3.5.8), as well as the symmetry measures derived from the Flip Test software (section 3.5.9). All measurements taken and analyses performed were standardised across Experiments 2 – 4 allowing for the inter-experimental comparisons, to be discussed in Chapter 9.

7.4 Results from Roe metrics

7.4.1 Basic dimensional measures

Given the potential bias created by the instruction of the cultural parent and the resultant focus on handaxe thinning, it was expected that basic dimensions would remain in line with the base target form. Length was immediately lost in Generation 1 and did not properly recover until Generation 5 (Figure 7.2). Despite the initial shortening of handaxe size, no real trend developed and iterative change was random (R^2 = 3.418, p = 0.128). The same could be said for thickness (R^2 = 0.3801, p = 0.131). However, for handaxe breadth, there was a significant upward trend with the last three generations growing on an iterative basis and strongly outperforming the base target form (R^2 = 0.752, p = 0.005), (see Figure 7.2). On this basis, with a fairly static length and thickness achievement, it could be assumed that the increase in breadth was having the effect of creating larger handaxes that were proportionately thinner. In terms of the relative success of the transmission bias, these measures in isolation could lead to a positive conclusion regarding the maintenance of form and the success of the cultural parenting strategy. However, over multiple generations of copying, with only basic dimensional measures, the effect of change on overall form remained unclear. Were handaxes becoming larger and therefore only relatively thinner and more crucially, where on the handaxe was the increase in breadth occurring? Without this information, it was impossible to gauge the impact of the TCP in general, and specifically, whether it was creating handaxes that were more or less pointed than the base target form. Those factors are addressed in the following sections.

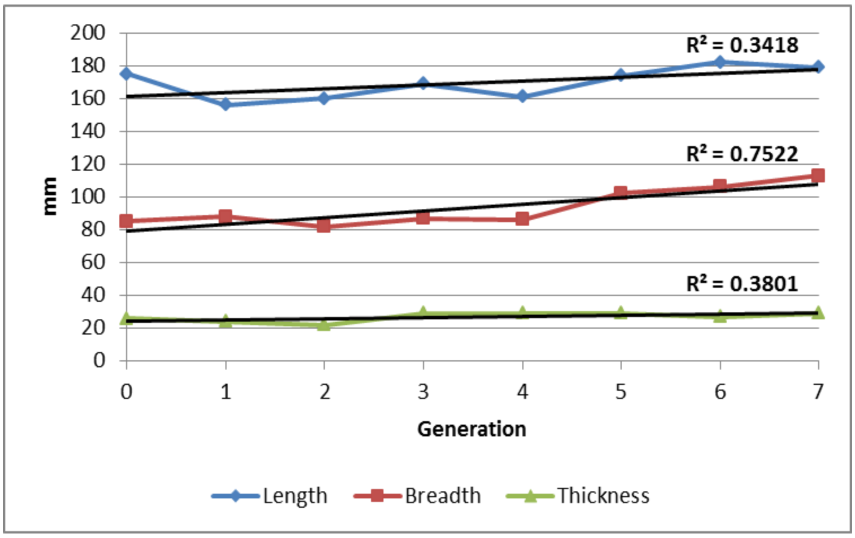


Figure 7.2. Trajectory of the basic linear measurements for the chosen forms passed through the TC (length, p = 0.13; breadth, p = 0.005; width, p = 0.13).

7.4.2 Refinement measures

Roe's ratio system now formed the second stage of evaluating the effect of one-to-one expert instruction from a cultural parent. The ($\frac{Th}{B}$) and ($\frac{T1}{L}$) ratios were the initial basis for the refinement measures. Figure 7.3 is a scatter plot of those ratios showing that for twelve knapped handaxes (two broke and were therefore discounted), when compared to the original target form, the majority (ten) had thicker tips relative to length, when compared with the original target form ratio of 0.069. However, six of the ten handaxes were within +/-0.01 of the target form, a small degree of variation, indicating that this aspect of refinement could be managed accurately 60% of the time. When the trajectory of the chosen form was plotted as it passed through the TC, for each refinement ratio separately (Figure 7.4), the resultant lines were relatively flat. Neither displayed a significant relationship ($\frac{Th}{B}$, R^2 = 0.116, p = 0.41; $\frac{T1}{L}$, R^2 = 0.167, p = 0.31) suggesting both attributes were not subject to strong directional trends and refinement was relatively well governed under the TCP of Experiment 3.

When viewed together, the trend towards increased breadth shown in Figure 7.2 was to some extent negated in the $\frac{Th}{B}$ ratio of Figure 7.4, by increasing thickness. So, in terms of refinement, the effect of the cultural parent appeared to be one of maintaining the relative balance between individual attributes. In an attempt to gain a better understanding of the interaction between the Roe refinement ratios, Figure 7.5 combined both ratios (4 measures) and showed there was difficulty in achieving both attribute ratios simultaneously, especially by the latter knappers, which created a spiral or oscillating movement around the base target form. To an extent, this pattern (as previously) was a function of the two dimensional nature of the Roe ratios, however, part of that relationship may also have been a product of instruction from the cultural parent. It is likely that as the novice was focusing on the area he/she was being instructed on, that attribute may have been achieved but to the detriment of different attributes that were not the focus of the knapper's attention. This idea is explored further in the following sections, and a better reflection of the impact achieved by one-to-one expert instruction is presented in section 7.6.1, when area based measures were used in conjunction with the linear based Roe measures.

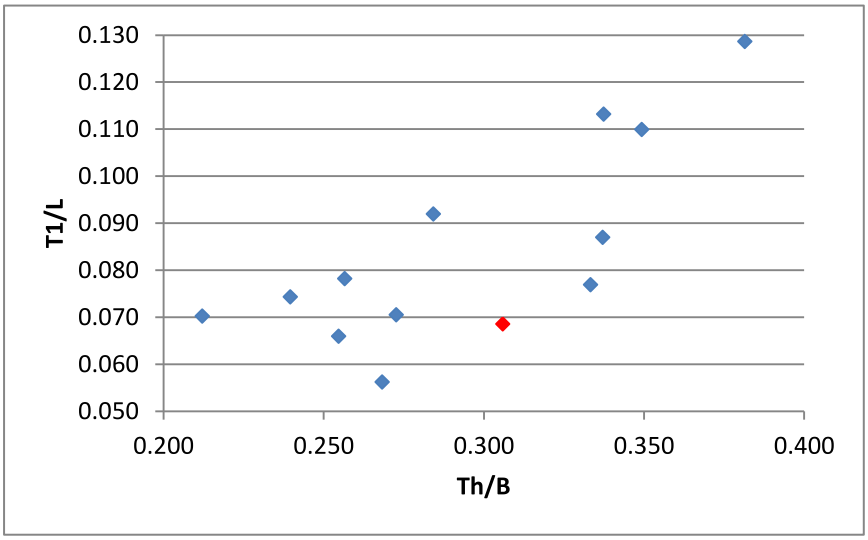


Figure 7.3. Scatter showing all pointed handaxes, the base or initial target form is highlighted in red.

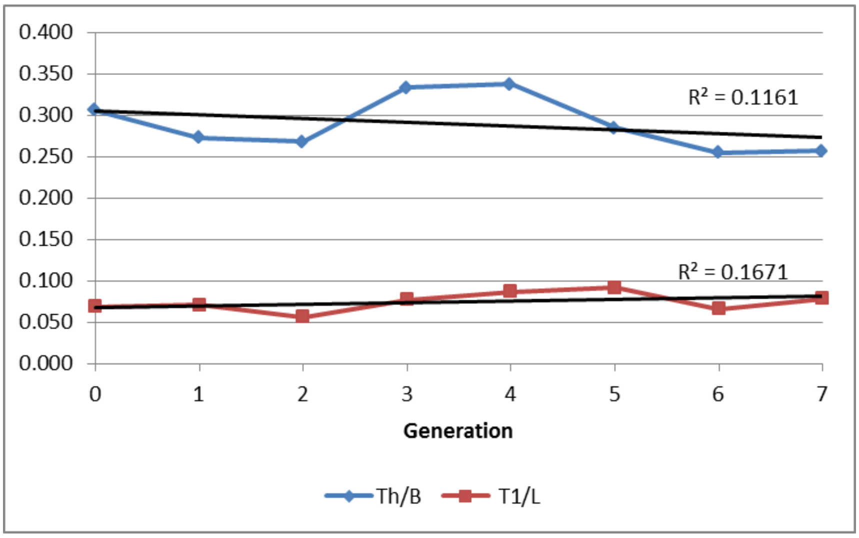


Figure 7.4. Trajectory of chosen form refinement ratios, by knapping generation ($\frac{Th}{B}$, p = 0.41; $\frac{T1}{L}$, p = 0.31).

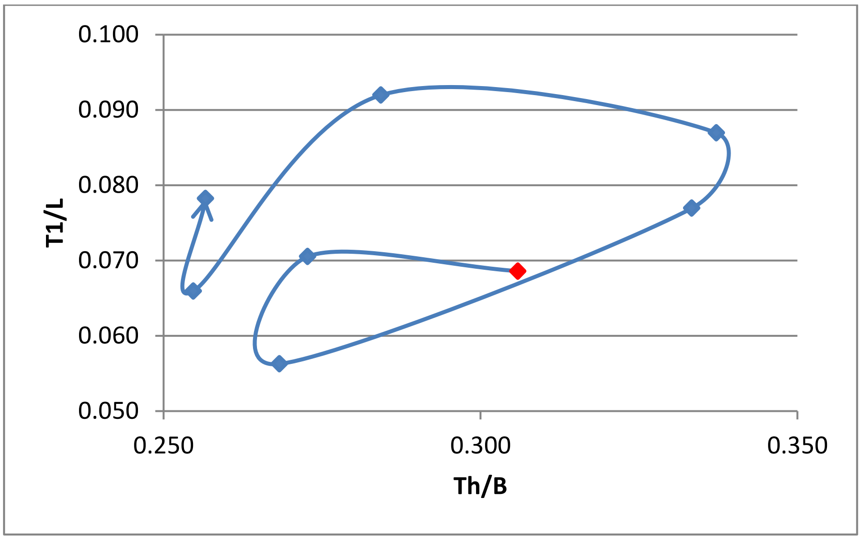


Figure 7.5. Refinement path of chosen pointed handaxes with the base target form highlighted in red; the direction and final iteration of the TC is indicated by the arrow.

7.4.3 Shape measures

Initial planform evaluation of the chosen Experiment 3 pointed handaxes was conducted using the three Roe shape ratios ($\frac{B}{L}$, $\frac{B1}{B2}$ and $\frac{L1}{L}$). Employing the same approach conducted in Experiment 2 but for the Experiment 3 TCP, the following figures plot the connection between the standard $\frac{B}{L}$ ratio and $\frac{B1}{B2}$ and $\frac{L1}{L}$.

On the basis of the hypothesis mooted at the end of section 7.4.2, if there was an element of influence from the cultural parent that led to success in the achievement of some attributes at the expense of others (those not the direct focus of instruction), it was expected that levels of ratio variation would behave differently in terms of their respective significance and effect on transmission of handaxe form. In the first instance, the scatter of all knapped handaxes (Figure 7.6) shows there was a diverse range of overall attribute achievement, but from that scatter, a more distinct trajectory of form emerged from the handaxes chosen to pass through the TC (Figure 7.7). This was likely a product of knappers responding to instruction from the cultural parent and trying new and different techniques to achieve the desired thinning techniques, which in one handaxe and for one attribute, may have had positive effects, but did not in the other. The fact that where choice was available, (in four out of five generations or 80% of the time), it was the first handaxe knapped that was chosen to pass through the TC in preference to the second, suggests the direct effect of the cultural parent was stronger when knapping the first preform blank. Two generations of the seven were excluded because in each of those cases, one of the preform blanks broke during the knapping process, meaning no choice was available. Interestingly, in both cases it was the first preform blank that broke, likely a result of the knapper being directed into unfamiliar territory by the cultural parent. Subsequent discussion with the cultural parent (BB) revealed that he did place more direct emphasis on instruction during the knapping of the first handaxe.

The idea of knappers being guided by their cultural parent but struggling with the achievement of attribute co-occurrence, such as $\frac{B1}{B2}$ and any other feature, was illustrated by the fact that the handaxe with the second highest $\frac{B1}{B2}$ ratio of 0.705 also had the closest $\frac{B}{L}$ ratio (0.503) to that of the base target form (0.486). Also, of the 4 handaxes with the closest $\frac{B1}{B2}$ ratios, only two were passed on through the TC as chosen forms (see Figure 7.6 and 7.7), meaning in these specific cases, achievement of other attributes was being passed on at the expense of $\frac{B1}{B2}$ proportions, which behaved randomly ($R^2 = 0.034$, $p = 0.66$).

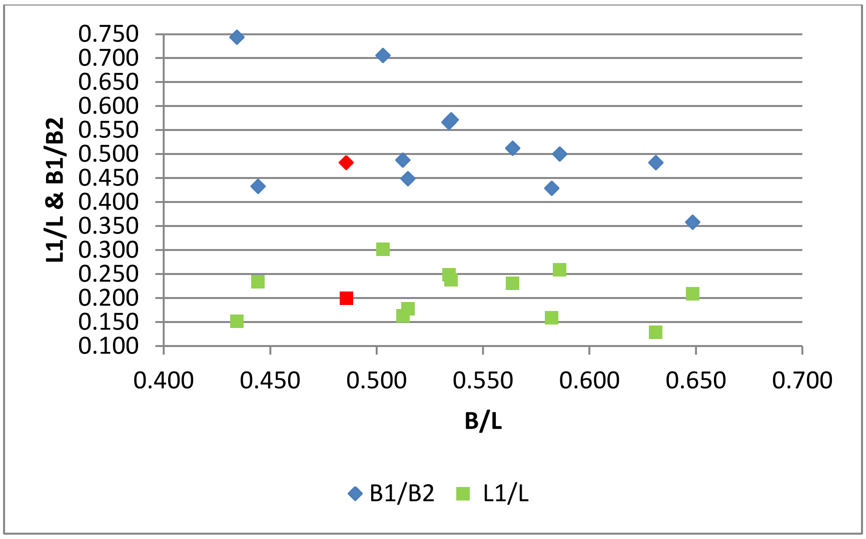


Figure 7.6. Scatter of all knapped handaxes showing wide levels of variation; $\frac{L1}{L}$ & $\frac{B1}{B2}$ are plotted against $\frac{B}{L}$ on the *x*-axis. Each TC's base target form is highlighted in red.

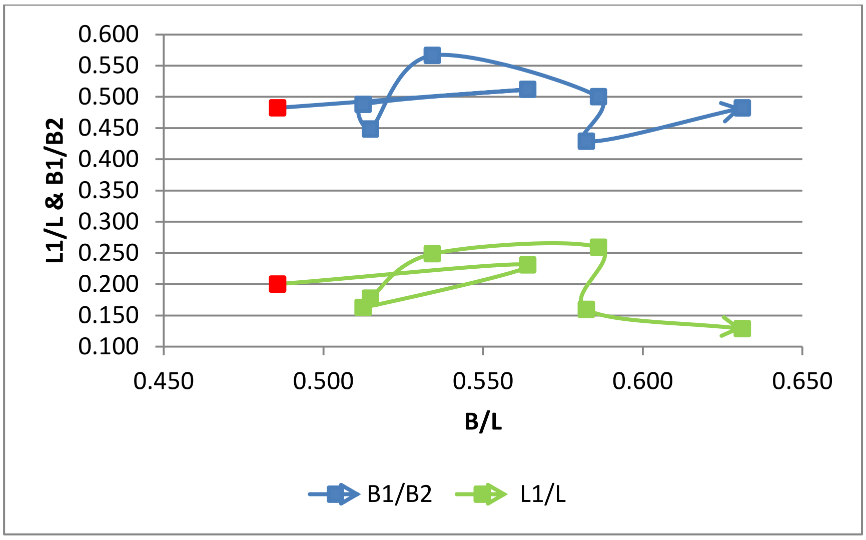


Figure 7.7. The path of the chosen handaxes according to the Roe shape measures. The largest change in $\frac{B}{L}$ occurred in the first iteration. $\frac{B1}{B2}$ & $\frac{L1}{L}$ followed similar patterns.

As concluded in Experiment 2 (and mentioned in 7.4.2), because of their linear nature, the Roe ratios make it difficult to gauge form or shape change for the whole area of the piece. A general TC trajectory for all shape measures of the chosen forms is illustrated in Figure 7.8, where the directional increase of $\frac{B}{L}$ can be viewed on a generational basis, showing a significant trend to become wider relative to length. With an R^2 value of 0.67 (p = 0.013), the relationship between

$\frac{B}{L}$ and the linear progress of the generations in the TC was rated as relatively meaningful and linked to non-random factors in the knapping process such as lack of relevant skill, or impact of the cultural parent. Figure 7.8 also shows the $\frac{B1}{B2}$ and $\frac{L1}{L}$ ratios, which tend to move more randomly (i.e. less directionally) but in tandem with one another, with the exception of the last iteration where in terms of proportion, but not dimension, $\frac{B1}{B2}$ is close to the base target form but L1 is much closer to the butt of the handaxe ($\frac{L1}{L}$ = 0.128). In combination, this meant its shape was almost triangular as opposed to pointed, in the manner of the target form and again illustrates the telling nature of $\frac{L1}{L}$ as a measure of handaxe shape, when compared to the other Roe measures. It also illustrates the need for further measures to convey a more complete nature of form change, on an inter-generational basis. Using purely the Roe measures to try and achieve this, Figure 7.9 combines a refinement measure $\frac{T1}{L}$ with $\frac{L1}{L}$, which shows that while the first three generations are relatively close to the target form in terms of $\frac{L1}{L}$ and $\frac{T1}{L}$, the following iterations deviate considerably, with the last two approaching a triangular planform shape due to low $\frac{L1}{L}$, after variation from thick tip to length measures. However, it still remains difficult to see just how the handaxes have changed in overall shape, size and area.

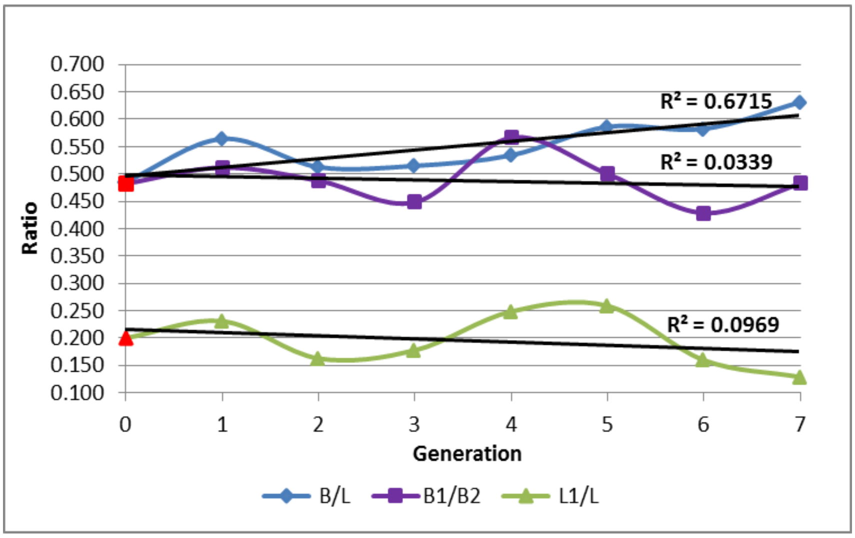


Figure 7.8. Generational movement of Roe shape measures ($\frac{B}{L}$, *p* = 0.013; $\frac{B1}{B2}$, *p* = 0.66; $\frac{L1}{L}$, *p* = 0.45).

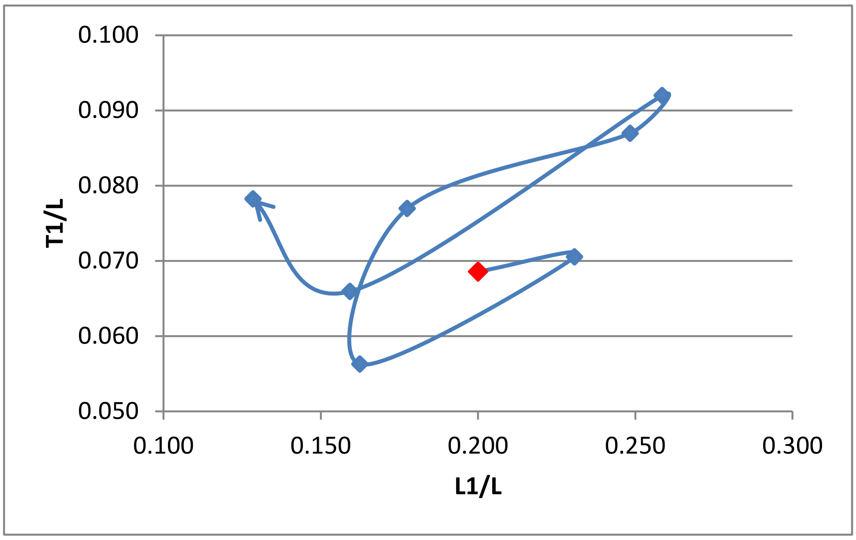


Figure 7.9. Using Roe measures to convey more aspects of transmitted refinement and shape. Levels of triangularity of form and thickness of tip to length can be ascertained but there is still difficulty in gauging what this meant in terms of overall form change.

7.5 Measures of Taper and 3D Euclidean Distance

Initial ideas on change in handaxe size and shape can, in this instance, be gained from using Roe ratios in combination with a basic measure of handaxe weight. This was because for pointed handaxes, the widest measure (B) should be in the bottom third of its length, so the increases in $\frac{B}{L}$ indicated by Figure 7.8 should be reflected by similarly significant increases in overall weight, likely stemming from the butt end or largest part of the pointed handaxe, which in the case of Experiment 3 they were ($R^2 = 0.67$, $p = 0.013$), see Figure 7.10 below. However, despite the fact that Figure 7.2 also showed an increase in length and breadth for the last 3 generations of copying, it still remained relatively difficult to quantify what the upward trend in handaxe weight meant in terms of overall or 3 dimensional changes to shape and size. On the basis that there was instruction from the cultural parent, it was expected that the Euclidean distance from the base target form would be lower than it was in Experiment 2. It was also hypothesised that the effect of one-to-one instruction would mean transmission of handaxe taper displaying variation that was more random in nature, as opposed to cumulatively directional due to the compound effect of insufficient skill levels, as in an uninstructed TCP.

In-line with the first hypothesis, the cumulative Euclidean distance travelled from the base target form was less in Experiment 3 than in Experiment 2: after 7 generations of copying the figures were 28.44mm and 44.6mm respectively (and 35.37mm in Experiment 2 after 8 generations of copying). The Experiment 3 data did produce significant results (*p* = 0.03) and there was an upward trend, linking the increase in Euclidean distance to the performance of the knapping generations in the TC, but R^2 = 0.554 (Figure 7.11) indicated that the relationship was marginal and less strong than for Experiment 2 (Figure 6.16b).

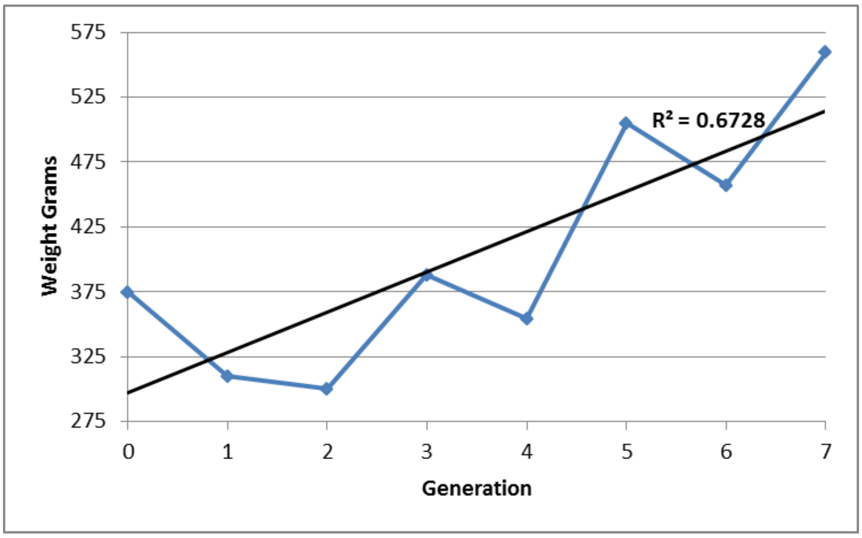


Figure 7.10. The upward trend in chosen form handaxe weight, when subject to a TCP of one-to-one expert instruction (*p* = 0.013).

The marginal or lesser R^2 value for Euclidean distance pointed towards reduced strength in the directional nature of the evolution of form in the cultural parent TCP. However, to understand what was happening on a generational basis meant looking at Euclidean change in conjunction with the ratios. The extreme shift in $\frac{B}{L}$ between the base target form and the first generation of copying (Figure 7.7), when looked at as part of the wider dynamics of handaxe form, can, as shown in Figure 7.12, mean that when adjusted for length, iteratively, the shape or degree of taper did not change that greatly (0.03 or 3%) from the target form. Yet, in terms of overall distance as a function of length, width and thickness, there was a sizeable change of 19.33mm; so in this case, a relatively accurate degree of taper had been achieved and transmitted through the TC, but at the expense of handaxe size. As a trend, this did not continue (R^2 = 0.46, Figure 7.13) and by generations 6 and 7 taper had increased to 0.549 and

0.540 respectively and Euclidean distance to 22.16mm and 28.44mm. This meant that a more pointed handaxe had evolved (especially Generation 6), which had also changed radically in terms of total Euclidean distance or overall size.

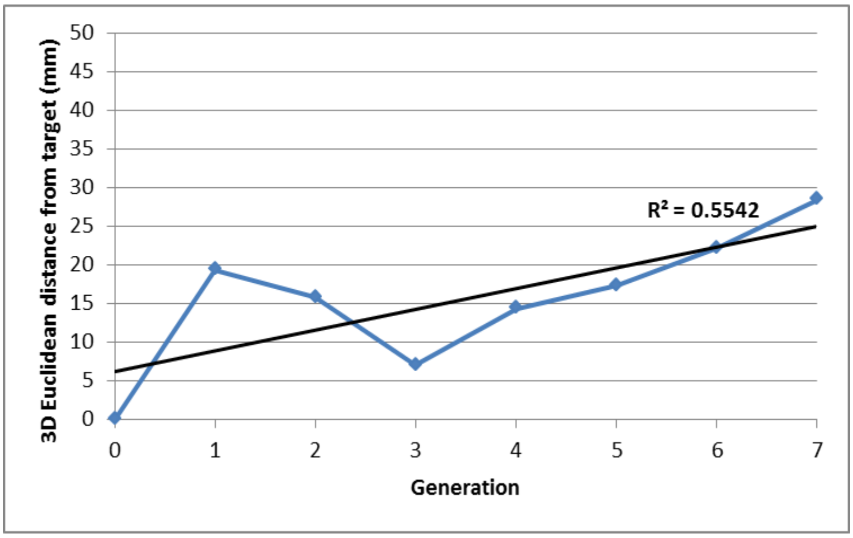


Figure 7.11. 3D Euclidean distance of chosen forms, from base target form, by knapping generation (p = 0.034).

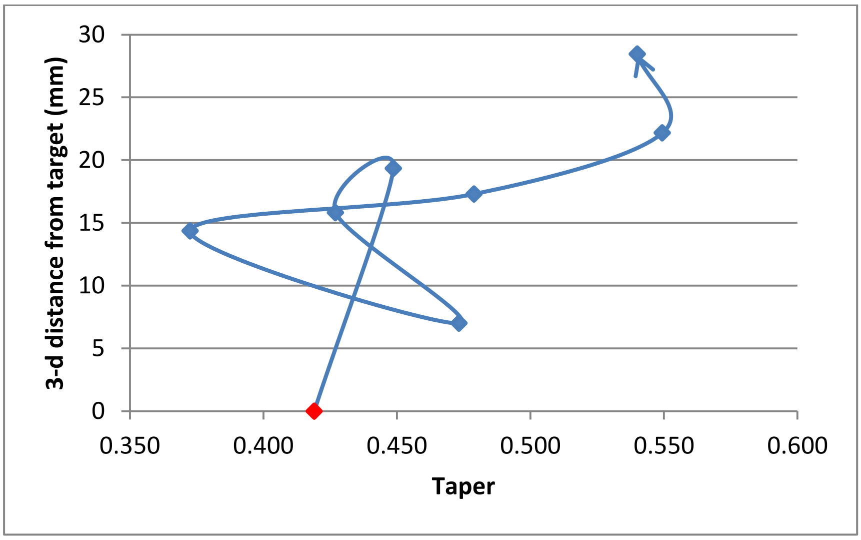


Figure 7.12. Using taper and Euclidean distance to more effectively gauge shape change.

The less directional and more random nature of shape change in Experiment 3 was also illustrated by the inclusion of $\frac{L1}{L}$ (R^2 = 0.097, p =0.45), which showed that for three generations of transmission, it was directionally the same as the taper measure. This meant that the pointed nature of the form (i.e. the balance of the handaxe's widest point relative to the location of B2) was being achieved. After this point, the $\frac{L1}{L}$ line mirrored or moved in opposition to taper (Figure 7.13), meaning the distance between them was growing, to the point that L1 was below B2 for iterations 6 and 7, confirming the fact that in the latter generations of the TC, the handaxes were becoming more triangular as opposed to pointed in shape (see Appendix 5 for photos of all chosen forms). These were informative measures of form change as the handaxes passed through the TC. However, with regard to actual size compared to the base target form, measured by the Euclidean distance travelled, there was still a shortcoming due to the nature of the formula (i.e. the squaring of distances to produce a positive sign). The resultant measure meant it was impossible to tell if the Euclidean distance was actually smaller or larger than the base target form. This issue will be addressed in section 7.6 with the addition of area based measures (cm²) to the evaluation process.

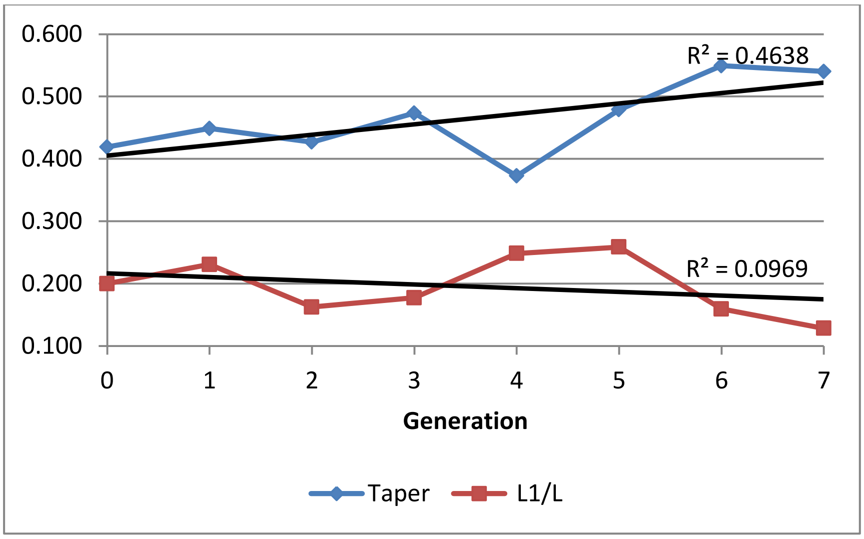


Figure 7.13. Illustrating the use of $\frac{L1}{L}$ in combination with new measures, to fine-tune where shape change such as taper was actually occurring. Here, in the latter iterations, increased taper was accompanied by *L1* moving down the handaxe, indicating the emergence of a more triangular form.

7.6 Area based measures of refinement and shape from ImageJ

7.6.1 Edge and planform area

The issue of actual size change was addressed by the use of the planform area measures produced from the use of ImageJ software. Roe's thickness measure (*Th*) was used in preference to the edge area measure derived from digital imaging due to the issues of consistency discussed in Chapter 3. Table 7.1 shows an 8.81% fall in *ADVA,* from the 103.38cm² of the base target form to 94.27cm² in the first iteration, accompanied by a near equivalent drop in thickness of 7.69%. These corresponding losses were partially a result of scaling due to the smaller handaxe size, but also linked to the knapper experiencing difficulty in managing the skills to accurately thin the handaxe, whilst also maintaining size and planform symmetry. After that point, iterative changes for *ADVA* area measures fell and rose alternately on a substantial basis, finishing on iteration 7 with the largest handaxe of the TC (*ADVA* = 138.72cm²), whilst for handaxe thickness, after Generation 3 the basic linear measure began to stabilise. Figure 7.14 shows the upward nature of that trend ($R^2 = 0.61$, $p = 0.02$) illustrating the relative strength of the relationship between intergenerational copying and increasing handaxe size when subject to cultural parenting. In terms of refinement, there was also a relationship represented by Roe's *Th* measure, although not as strong ($R^2 = 0.38$, $p = 0.10$).

Generation	Thickness (Th)	ADVA	% +/- Th	% +/- ADVA
Base Tgt (0)	26	103.38	-	-
1	24	94.27	-7.69	-8.81
2	22	90.31	-8.33	-4.21
3	29	99.41	31.82	10.08
4	29	93.58	0.00	-5.86
5	29	127.37	0.00	36.10
6	27	119.77	-6.90	-5.97
7	29	138.72	7.41	15.82

Table 7.1. Iterative measures of average handaxe planform areas (cm²) and Roe's thickness measure (mm).

To present a picture of how refinement and handaxe size were interacting, the +/- iterative changes, not aparent from the Euclidean measures, are shown by the trajectories in Figure 7.14. A cursory inspection of iterational changes in thickness (*Th*) and *ADVA*, viewed individually, gave the impression of cultural transmission not operating within the low boundaries associated with perceptual limitations alone (Chapter 2). Those changes were then presented as a ratio produced by dividing thickness by the square route of *ADVA* ($\frac{Th}{\sqrt{ADVA}}$), and shown alongside Roe's $\frac{Th}{B}$ and $\frac{T1}{L}$ ratios (Figure 7.15), to provide a more complete picture of the effect of the Experiment 3 TCP. From a base target ratio of 0.069, $\frac{T1}{L}$ varied very little in a directional sense ($R^2 = 0.17$, $p = 0.32$), indicating that whatever the size of the handaxe, its tip was always refined in relation to, or in proportion to its overall length. $\frac{Th}{\sqrt{ADVA}}$ was also illustrating the point that the growth in handaxe area (cm²), illustated by the last generations of the TC (Figure 7.14) did not mean a less refined handaxe was being produced. Quite the opposite was true, as $\frac{Th}{\sqrt{ADVA}}$ was lower for iterations 5 – 7 than it was for iteration 4 and also that of the base target form (Figure 7.15). So, in this respect, the impact of cultural parenting on handaxe form was to preserve $\frac{Th}{\sqrt{ADVA}}$ and produce more refined handaxes; an aspect of knapping difficult to master in an environment operating with less stringent biases or controls.

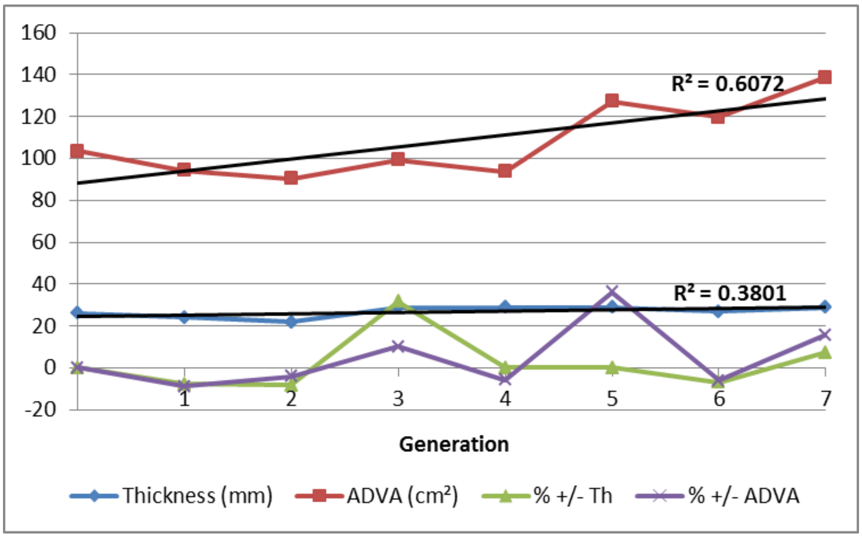


Figure 7.14. Total and iterative changes in *ADVA* and thickness measures, showing an upward trend in handaxe size (*ADVA, p* = 0.02; *Th, p* = 0.10).

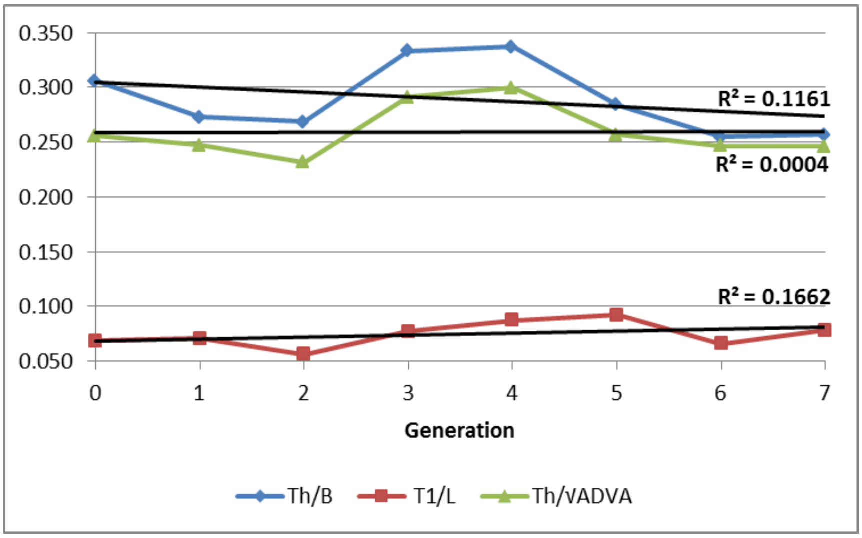


Figure 7.15. $\frac{Th}{\sqrt{ADVA}}$ presented with Roe refinement ratios showing regular transmission of handaxe refinement when subject to one-to-one instruction from a cultural parent.

7.6.2 Residual cortex area

As an extension to Roe based measures of refinement and the handaxe area based measures derived from ImageJ, residual cortex was also measured and calculated using ImageJ, as an alternative proxy for the transmission of refinement in handaxe manufacture. The resultant measures, expressing dorsal and ventral face cortex as a percentage of the total area of each respective face, both displayed random behaviour and no directional trends of statistical significance (Figure 7.16). However, as in Experiment 2, each knapping generation found it more difficult to match or control for the area of cortex remaining on the dorsal (%DC of DA) as opposed to the ventral face (%VC of VA). Following this, Figure 7.16 also shows that levels of $\frac{Th}{\sqrt{ADVA}}$, defining overall handaxe shape refinement, were more stable and varied less on an iterational basis than levels of dorsal or ventral residual cortex. On this basis, it seems likely that reducing levels of residual cortex was not striven for as a primary knapping aim. The idea that vestigial cortex was more likely a by-product of the overall knapping process in this scenario, was also supported by the fact that the percentage cortex lines only loosely followed the trajectories of $\frac{Th}{\sqrt{ADVA}}$ and the Roe refinement measures $\frac{Th}{B}$ and $\frac{T1}{L}$, and often ran counter to overall handaxe planform areas (Fig 7.14). In this context, even with one-to-one expert instruction from a cultural parent, the nature of residual cortex was one subject to high levels of iterational variation not necessarily reflected by other measures of refinement (Fig. 7.16). This, along with the weak R^2 values associated with cortex measures, supports the idea that when low levels of cortex were achieved, as a trait, it was more likely a knapping by-product achieved incidentally, as each knapping generation was striving to achieve and therefore transmit other attributes with greater significance, for example, overall levels of handaxe size or thickness (Figure 7.14).

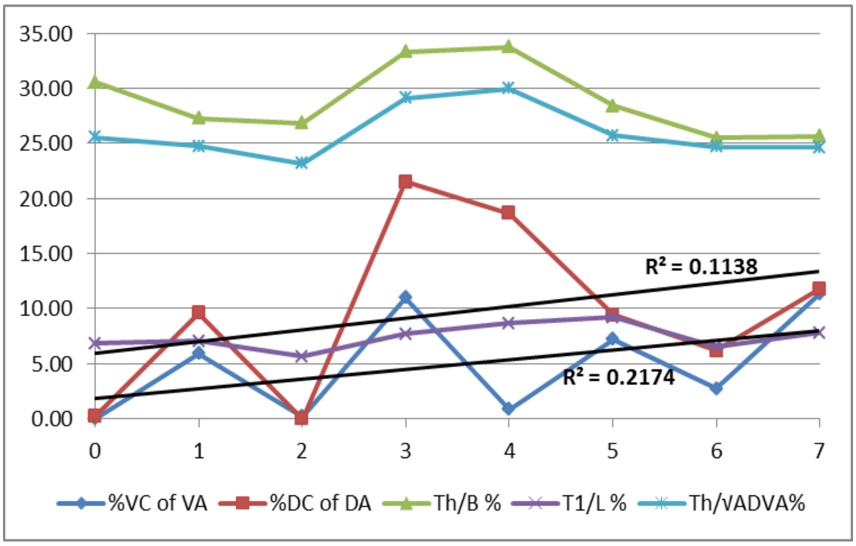


Figure 7.16. Chosen form dorsal and ventral cortex percentages presented against other handaxe refinement measures.

7.6.3 Handaxe shape measures

For the handaxes of Experiment 3, $\frac{Th}{\sqrt{ADVA}}$ presented a relatively stable picture, indicating that the balance of handaxe form (i.e. planform to cross-sectional shape), was changing very little (Fig 7.15). To gain a fuller picture of how handaxe shape was evolving, on an iterative basis, the following section draws together the most relevant measures from Roe's original ratios, the new geometric uses of those measures, and the area based measures derived from ImageJ (Table 7.2).

Generation	ADVA	ADVA % i change	% Taper	3D distance (mm)	L1/L %	B/L %
Base Tgt	103.38	0.00	41.90	0.00	20.00	48.57
1	94.27	-8.81	44.87	19.34	23.08	56.41
2	90.31	-4.21	42.71	15.81	16.25	51.25
3	99.41	10.08	47.34	7.00	17.75	51.48
4	93.58	-5.86	37.27	14.35	24.84	53.42
5	127.37	36.10	47.89	17.29	25.86	58.62
6	119.77	-5.97	54.95	22.16	15.93	58.24
7	138.72	15.82	54.00	28.44	12.85	63.13

Table 7.2. As a significant measure, Roe's $\frac{B}{L}$ shape ratio showed relatively small iterational changes but in terms of ADVA and 3D Euclidean distance, handaxe size was increasing; as was taper and degree of pointedness from $\frac{L1}{L}$, especially in the latter generations.

In the first instance, and by using a significant measure such as $\frac{B}{L}$ as a baseline to cross-check the stability of $\frac{Th}{\sqrt{ADVA}}$, it appeared that one-to-one transmission from a cultural parent had almost neutralised variation to the low levels expected if perceptual limitation was the only modifying agent. The largest $\frac{B}{L}$ change of 7.84% came in the first generation of copying. After that, variation ran at an average of 1.1% per iteration (Table 7.2). In this context, although the proportions of handaxe length to breadth and $\sqrt{ADVA}$ to thickness (Figure 7.15) were relatively faithfully transmitted attributes, there was also significant variation in other traits such as *ADVA,* which were more sensitive to modification because of skill or cultural parenting during the transmission process. The initial 7.84% $\frac{B}{L}$ drop was an early indication that skill levels required to knap the base target form may not have been possessed by the first knapper. The closeness of the following $\frac{B}{L}$ results perhaps reflected the similar levels of skill possessed by all other knappers in the TC, which permitted 'accurate' replication of a less refined form (than the base target), but only in terms of $\frac{B}{L}$ and $\frac{Th}{\sqrt{ADVA}}$ proportions, when aided by the one-to-one instruction of cultural parenting.

The first indication that a continual and cumulative change in form (planform size) had occurred was provided by the measure of 3D Euclidean distance from the base target, which started after one generation of copying at 19.34mm and finished at 28.44mm from the base target form after 7 generations of copying (Table 7.2). The upward trend of this three dimensional change in form is apparent from the 3D distance line in Figure 7.17, where $R^2 = 0.554$ ($p = 0.03$) indicated the existence of a relationship between change in Euclidean distance and inter-generational knapping performance. Specific and key shifts in form occurred in iteration 1 (as noted) and iteration 5, where Table 7.2 showed a significant increase in planform area from 93.58cm² to 127.37cm². In terms of generational change this represents the largest of any iterative shifts for any attribute (Figure 7.17). As with the shift in the first generation, the TC's shape trajectory did not recover from this; the degree of taper became more pronounced and $\frac{L1}{L}$ moved down the handaxe towards the butt. The overall result of these shifts was to produce a cumulative evolution in form that was responsible for the emergence of a larger, more tapered handaxe that was more triangular in shape than the base or original target form (Appendix 5), but that maintained a relatively stable level of refinement as measured by a consistent level of thickness (*Th*). Based on the significance demonstrated by some of the key attribute measures, it is likely that the growth in handaxe size and the maintenance of this level of refinement throughout the TC was a direct result of the bias produced by transmission based on one-to-one instruction. Cultural parenting allowed for the development of a scenario where refinement could be achieved and maintained without a resultant long-term loss in overall handaxe size.

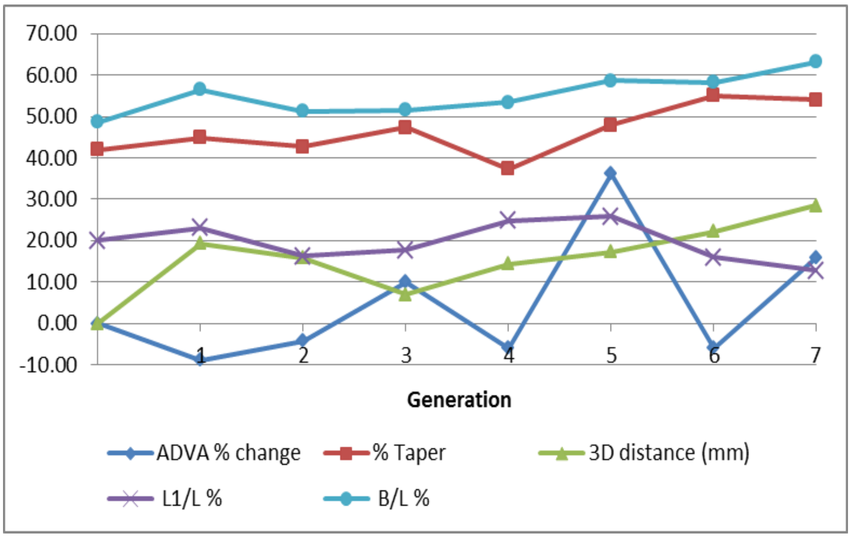


Figure 7.17. Graphic plotting shape and size changes, illustrating the necessity of having multiple measures for a full understanding of cumulative form change in TCs.

7.7 Symmetry

Levels of symmetry appeared quite erratic. There was no relationship between *VAI* and intergenerational transmission ($R^2 = 0.06$, $p = 0.54$) and the target level of *VAI* was achieved only 3 times in 7 generations of copying. On that basis, the main point of interest was the extensive level of variation on an iterative basis, for example, the movement from a *VAI* of 2.58 (very high) to 4.19 (moderate) between iteration 1 and 2 (Figure 7.18).

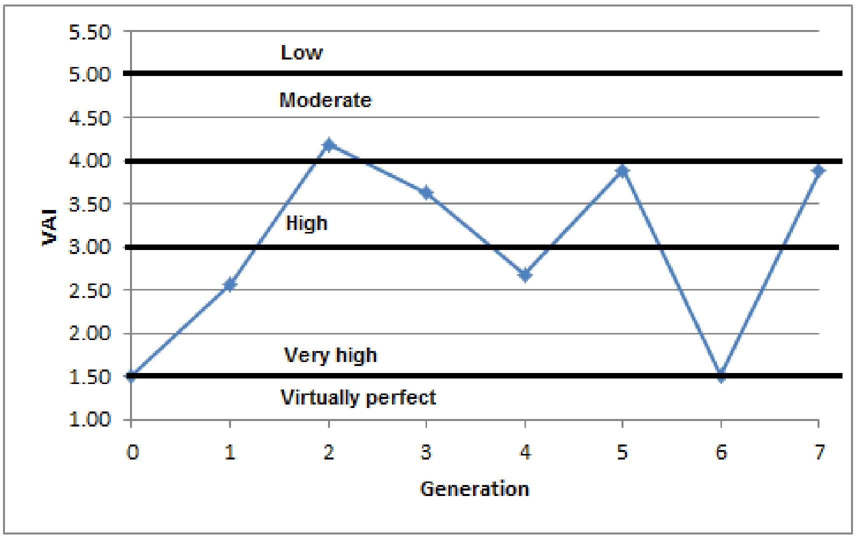


Figure 7.18. Handaxe asymmetry showing the tendency for *VAI* to move out of the 'Very high' range down into the 'High and Moderate levels.

The fact that symmetry was not reproduced accurately on an iterative basis was examined in relation to other traits, to discover if knapping priorities were being driven by the cultural parent. If this was the case, the focus of the knappers would be directed towards the reproduction of alternative attributes that they would find difficult to reproduce in a situation where they were uninstructed, and transmission was based solely on end-state copying. Figure 7.19 looks at handaxe size (*ADVA*), plotted against *VAI*. This indicated that for 4 of the 7 generations, size range was smaller than the base target form (103.38cm^2), but varied relatively little between 99.41 cm^2 and 90.31cm^2. However, the fact that the final three generations increased to 127.37cm^2, 119.77cm^2 and 138.72cm^2 respectively, suggests that planform size in isolation was not the factor being regulated by cultural parenting, but as noted previously, it did mean there was no long-term loss in handaxe size. Conversion of *ADVA* into a refinement ratio ($\frac{Th}{\sqrt{ADVA}}$), provided a better indication of how cultural parenting affected handaxe form. Figure 7.20 shows a tight $\frac{Th}{\sqrt{ADVA}}$ grouping of between 0.257 and 0.300. In this respect, even the larger handaxes were being controlled on the basis of refinement or thickness relative to planform size; their ratios of 0.257, 0.247 and 0.246 (all lower than or comparable with the base target ratio of 0.256) indicated that this was a strongly transmitted attribute, also taking precedent over a dispersed achievement of $\frac{L1}{L}$ or degree of pointedness (Figure 7.21).

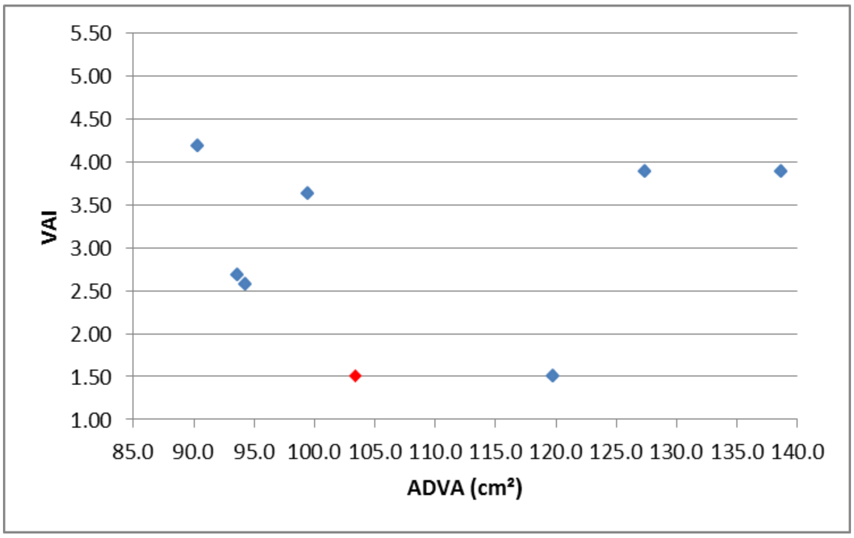


Figure 7.19 *ADVA* and *VAI*. Dispersed groupings indicate that planform size was not the primary focus of instruction and cultural parenting

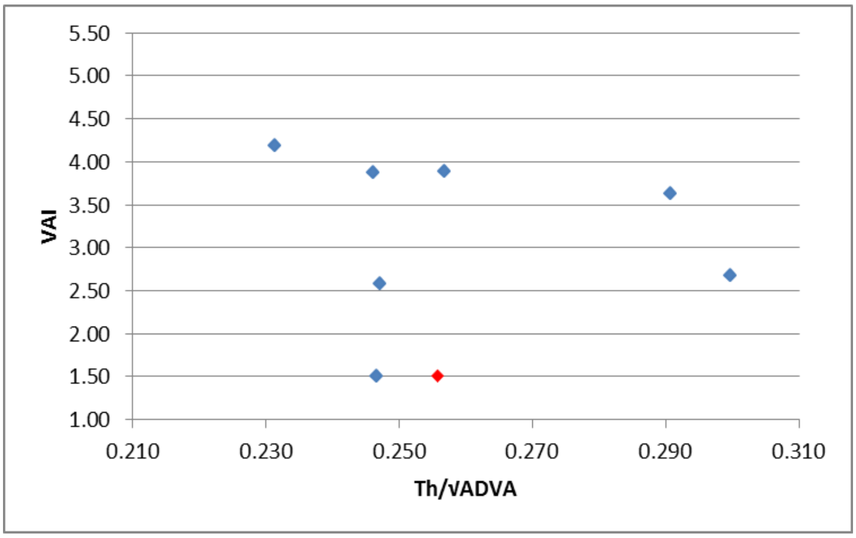


Figure 7.20 $\frac{Th}{\sqrt{ADVA}}$ & *VAI* showing small variation indicating that handaxe refinement, on the basis of thickness to planform size, received biased attention and was transmitted strongly as a result of cultural parenting.

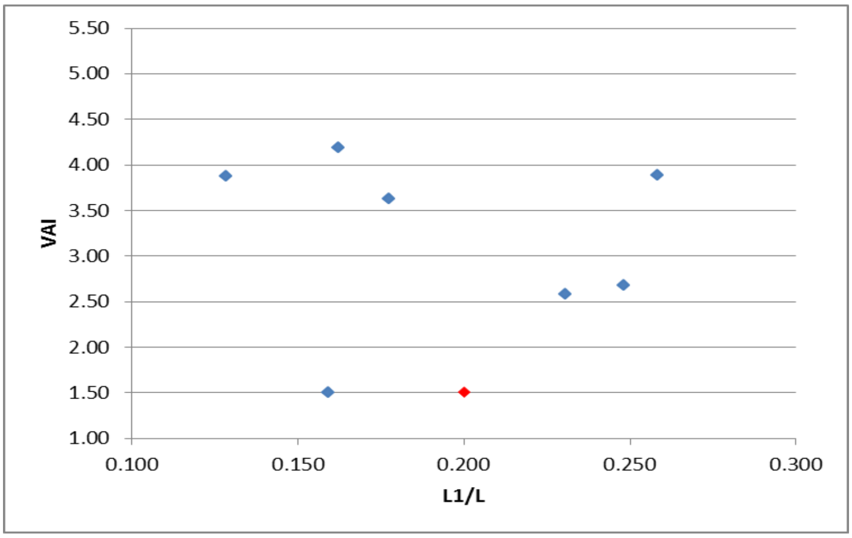


Figure 7.21. $\frac{L1}{L}$ formed two main clusters but iterationally, it was not transmitted as consistently as $\frac{Th}{\sqrt{ADVA}}$.

To qualify the poor performance of symmetry in Experiment 3 (i.e. achievement of base target form VAI level only 3 out of 7 times), Table 7.3 shows how other shape and refinement attributes took precedent over symmetry in the instruction regime of the cultural parent. This was particularly relevant for refinement ratio $\frac{Th}{\sqrt{ADVA}}$, where the variation of the mean ratio of chosen form handaxes, from that of the base target form, was only 1.6%. Breadth in relation to length increased steadily as the TC progressed, which in this context also reflected the impact of the cultural parent's handaxe refinement strategy, as handaxe width was not proportionately lost during the thinning process.

Generation	B/L	B1/B2	L1/L	Th/√ADVA	ADVA
base tgt 0	0.486	0.482	0.200	0.256	103.38
1	0.564	0.512	0.231	0.247	94.27
2	0.513	0.488	0.163	0.232	90.31
3	0.515	0.448	0.178	0.291	99.41
4	0.534	0.566	0.248	0.300	93.58
5	0.586	0.500	0.259	0.257	127.37
6	0.582	0.429	0.159	0.247	119.77
7	0.631	0.482	0.128	0.246	138.72
Total	3.925	3.424	1.366	1.819	763.410
Mean (Gen 1 - 7)	0.561	0.489	0.195	0.260	109.059
% from base tgt	15.455	1.419	-2.451	1.631	5.498

Table 7.3. Mean variation form base target form for chosen form shape and refinement ratios.

7.8 Conclusion

With regard to the evaluation of one-to-one expert instruction from a cultural parent, Roe's measures provided ratio based evidence of dimensional change throughout the course of the TC, but not an accurate indication of the effect that change was having on the actual form of the handaxes as three dimensional artefacts. Early indications from the Roe refinement and shape ratios of the TC in Experiment 3 were that handaxes were becoming wider relative to length ($\frac{B}{L}$), with a failure to simultaneously replicate tip thickness to length ($\frac{T1}{L}$) and thickness to breadth ($\frac{Th}{B}$). The addition of taper and Euclidean distance measures revealed that handaxes, as well as becoming more pointed, were radically changing in size. However, it was not until the addition of planform area measures (in preference to purely linear measures of size), especially in combination with the index of asymmetry, that the evaluation process was able to convey changes in handaxe form as a whole, and begin to relate to the knapping process that was creating them.

The direct effect of the bias created by cultural parenting was to force the knappers into focusing on handaxe refinement and managing the relationship between thickness relative to overall planform size. Experiment 2 (Chapter 6) had already shown this was a difficult relationship to manage. Consequentially, the seemingly easier knapping default of maintaining and transmitting high levels of planform symmetry as a trait became less dominant, as indicated by the erratic iterative nature of the *VAI* in Experiment 3. There were two *ADVA* size groupings within the TC of Experiment 3, the first smaller than the base target form, followed by three iterations of handaxes larger than the target form. Although representing deviation from the target, the latter group was further evidence that cultural parenting was able to maintain and transmit $\frac{Th}{\sqrt{ADVA}}$ as a trait, without the resultant long-term loss in overall handaxe size. As illustrated by Experiment 2 (Chapter 6), loss of size was more likely the case in a situation of uninstructed end-state copying (or low skill level), due to the reductive nature of the knapping process.

Cultural parenting, by its very nature, is a mode of transmission where there is a heavy amount of instruction. In such situations, knappers are often trialling new techniques suggested by their instructor. Due to unfamiliarity, success in a new technique such as thinning the handaxe to maintain the $\frac{Th}{\sqrt{ADVA}}$ relationship, without losing handaxe size, may result in loss of focus in the achievement of other attributes. In Experiment 3, this resulted in changes of form that, even with the presence of a cultural parent, counter intuitively, did not result in exact replication of the target form or the expected low levels of overall attribute variation.

Chapter 8.

Experiment 4: the effects of many-to-one transmission from an accomplished peer group on copying pointed handaxes in a transmission chain

8.1 Introduction

On an inter-generational basis, operating with the bias created by one-to-one expert instruction, Experiment 3 has already demonstrated how variation in form can be affected differentially, when compared to the less restrained nature of uninstructed end-state copying (Experiment 2). Maintenance of handaxe refinement, gauged by the relationship between edge area and planform area, despite an initial decrease followed by and eventual increase in handaxe size, showed a degree of stability not present in the pointed handaxes of Experiment 2 (Chapter 6). This illustrates the direct impact that one-to-one expert instruction had on the knapping process and the resultant handaxe form. The counter-intuitive aspect of this particular example of teaching was the simultaneous variation or low levels of faithful transmission of other traits or aspects of handaxe form, such as planform size and notably, levels of symmetry. It was felt this was likely a result of the participant's attention being so effectively directed towards an aspect of knapping, requiring higher levels of skill to master, that their focus on the simultaneous achievement of attributes such as symmetry, transmitted faithfully in Experiment 2, was diminished. Experiment 4, the subject of this chapter, focused on another likely mode of Acheulean transmission: accomplished peer group instruction. Here, in contrast to the previous experiments, the focus was also on the group in the cultural transmission process, as opposed to exclusively the individual; a difference reflected in the following objectives.

8.1.2 Objectives

- To explore and evaluate how the pointed handaxe form of the experienced novice knapper evolved through the multiple generations of a transmission chain, when subject to a less direct form of instruction (compared with one-to-one). This transmission bias was created by knapping in groups comprised of peers who were accomplished knappers, which enabled the provision of instruction on a many-to-one basis.
- To ascertain whether the effect of accomplished peer group interaction would create any significant group based inter-generational differences, in terms of handaxe size, shape and refinement.

8.2 Methodology

8.2.1 Transmission chain protocol and target form

Accomplished peer group instruction (in the context of Experiment 4), meant using an open group transmission chain (Chapter 2) to explore the concept of knapping and instruction on an informal, many-to-one basis. Each generation was comprised of four members and the TC consisted of six generations in total. Although the four members of each generation were peers, three of them were more experienced knappers capable of fulfilling an instructional role but not on the level of a cultural parent. Each of those three members remained the same throughout the iterations of the transmission chain; the fourth and less experienced member of the group changed with each generation. Verbal and gestural interaction was permitted and encouraged between all members of each generation. The target form for each generation was visible and could be handled by all members throughout the course of each bout of knapping.

The base target form (for the first knapping iteration) was the same pointed handaxe used in Experiment 2 and 3 (Figure 6.1b). Also in common with the previous Acheulean experiments, each member of the TC was given two standardised preform cores from which to knap their handaxes. The closest match to the target form, produced by the novice knapper was chosen, by that novice, from his/her two cores. That copy then became the target form for all knappers in the succeeding generation and so on, until the end of the TC. On this basis (assuming no breakages), each generation would produce eight handaxes (two per member). Hammerstone selection also worked on the same basis as in Experiments 2 and 3. A selection of differing weights, sizes and textures was made available to the knappers (Figure 8.1) and they were able to select and change what they considered the most appropriate single or combination of hammerstones for each knapping task. All knapping was performed using hard hammer percussion; thinning was not undertaken using soft hammer of any kind, in any of the experiments.

Figure 8.1. The different sizes, weights and textures of hammerstone made available to all the knappers of Experiment 4.
Photograph: S. Page

8.2.2 Measurement

The levels of variation produced on an inter and intra-generational basis were captured, in common with the previous experiments by using, in the first instance, standard Roe measurement and ratios, followed by a geometric application of those measurements in the form of taper and 3D Euclidean distance (see section 3.5.6). The pixel based photo imaging software programs, ImageJ and Flip Test (sections 3.5.7 – 3.5.8 & 3.5.9 respectively) were then used to gauge, more realistically, how variation in attribute dimensions were actually affecting handaxe shape and size, within each group and as it passed through the generations of the TC.

8.3 Results from Roe metrics

8.3.1 Basic dimensional measures

The first stage in the evaluation process was the analysis of the basic dimensional measures of the chosen form of each novice knapper, as it progressed through the generations of the TC. It was expected that the effect of many-to-one instruction from an accomplished peer group would result in the emergence of a generational norm that the experienced novice knapper would adhere to. It was also hypothesised that variation within the transmitted form (or norm) of the novice knappers would be relatively limited because of the regulating effect of the TCP. Linear regression revealed a positive association between the knapping of each generation and the effect it had on two of the three measures: Length, $R^2 = 0.6746$ and Breadth $R^2 = 0.7978$ (Figure 8.2), with significant *p* values of 0.023 and 0.0068 respectively. The limited variation in thickness was not significant.

The significance of length and breadth, related to the downward trends in the intergenerational reproduction of both attributes, provided an initial indication that handaxes were becoming shorter and narrower, with thickness remaining stable (levels varied little between 25mm and 30mm). Specific to breadth, the downward trend was consistent through the TC, compared with length, where there was a degree of stabilisation in the middle generations, before a very erratic performance in Generation 6 (Figure 8.2). To a degree, this indicated that the influence of the many-to-one instruction may have been to establish a group norm for length, which, if Generation 6 was regarded as an outlier, was being transmitted as a trait more effectively and surviving over and above breadth and thickness. This result may appear positive in terms of the hypothesised effect of the TCP on handaxe form but length, breadth and thickness are only measures of single dimensions and are not adjusted to take account of their relationship to any other attribute. This linkage is an important factor when considering the heavy interplay involved in the knapping of multiple attributes on a simultaneous basis, and the more radical changes in form that the basic single attribute measures were likely masking. On that basis, the following sections use the basic metrics, employed as ratios, to analyse aspects of handaxe refinement and shape, as utilised in Roe's system of evaluation.

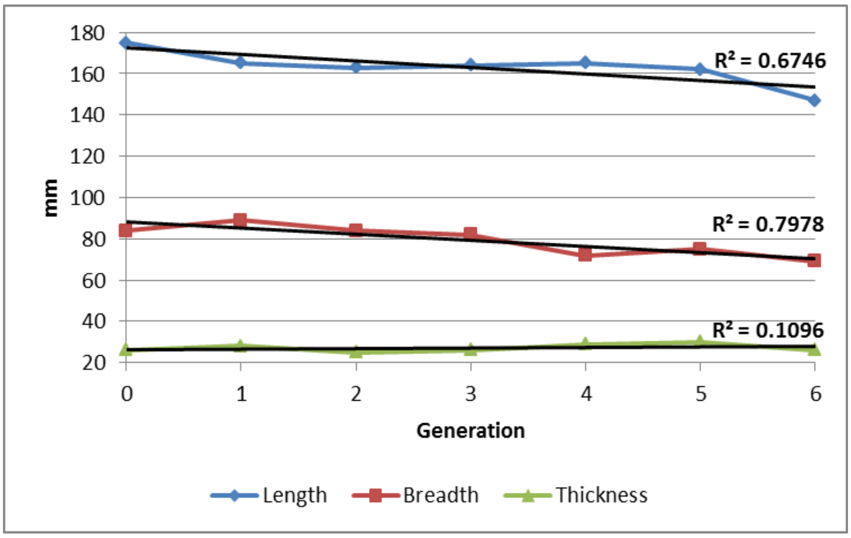


Figure 8.2. Trajectory of basic linear measures of length (p = 0.023), breadth (p = 0.0068) and width, for the novice chosen form handaxes, by generation.

8.3.2 Refinement ratios

The scatter of all handaxes knapped under conditions of accomplished peer group interaction, on first inspection, reinforced the most common conclusion of all experiments in the series: a failure to achieve the metric dimensions (defined by a single and largest measure of any attribute), achieved by the initial or base target form (highlighted in red, in Figure 8.3). All handaxes knapped by all members of the TC had a $\frac{T1}{L}$ ratio higher than the base target form and the majority (96%), were also thicker relative to breadth. For both measures, the effect of inter-generational knapping on the form change of the experienced novice chosen forms was relatively strong: for $\frac{Th}{B}$, R^2 = 0.664 and p = 0.02; for $\frac{T1}{L}$, R^2 = 0.599 and p = 0.04 (Figure 8.4a). With this in mind, the explanation for relatively extreme changes in refinement can partially be found in Figure 8.4b, which plots the trajectory of the chosen target form as it passed through the TC. The experienced novices in the first three generations reproduced and passed on $\frac{Th}{B}$ accurately, with little variation around the 0.306 ratio, but had difficulty maintaining $\frac{T1}{L}$; the tips of generations 1 and 3 both increased in thickness by 32% relative to their length. The novice in Generation 4 maintained $\frac{T1}{L}$, but in doing so passed on a handaxe that was much thicker relative to breadth, with a ratio of 0.403. This large shift effectively destabilised the TC, as the new attribute pattern was replicated relatively faithfully in iteration 5, but it was followed by another large copying error in Generation 6.

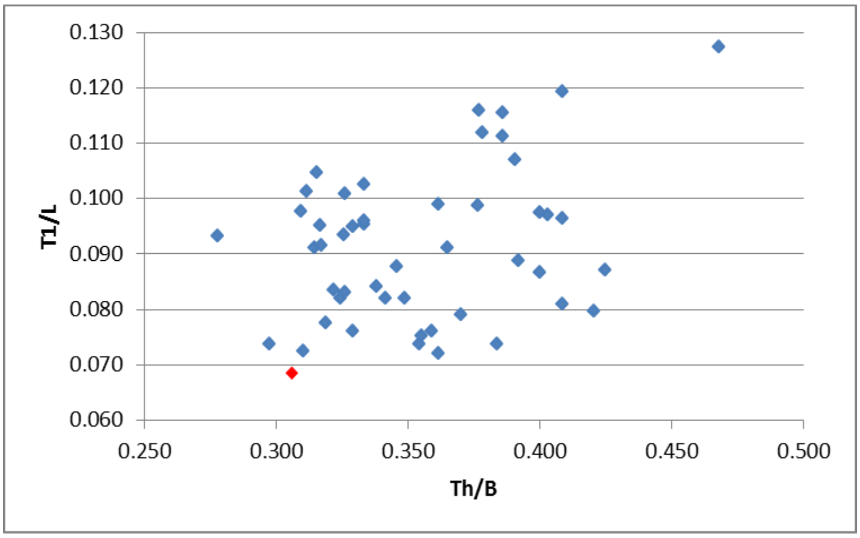


Figure 8.3. Scatter of all handaxes, from all generations, plotted using the Roe refinement measures of $\frac{T1}{L}$ and $\frac{Th}{B}$.

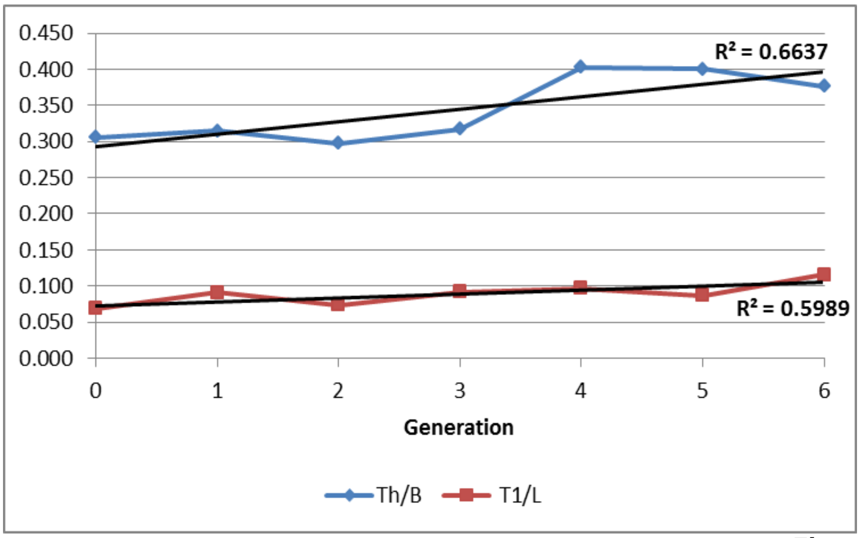


Figure 8.4a. Trajectory of chosen form refinement measures $\frac{Th}{B}$ (p = 0.02) and $\frac{T1}{L}$ (p = 0.04) by generation.

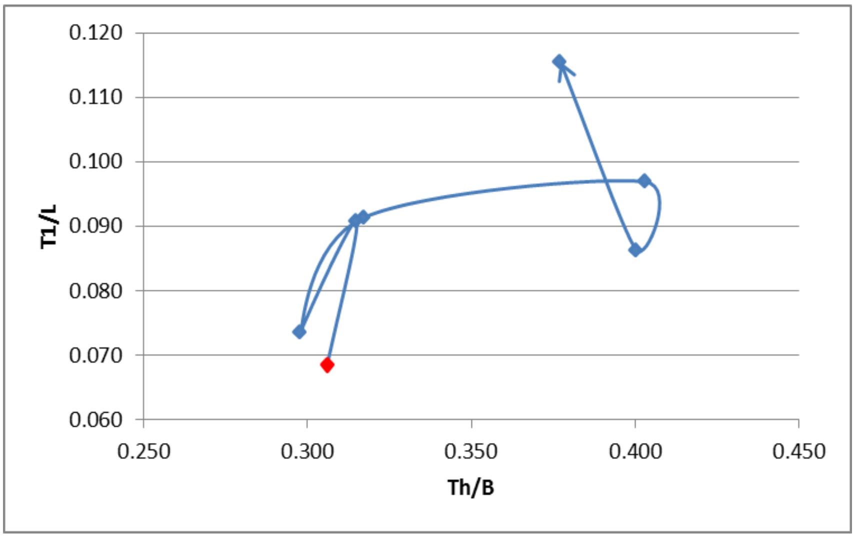


Figure 8.4b. Trajectory of chosen target forms, using refinement measures $\frac{T1}{L}$ and $\frac{Th}{B}$.

The most effective way of highlighting the dynamic of the TC and the generations within it, is illustrated by Figure 8.5a. From the very beginning of the process, effective transmission of Roe refinement measures was compromised; the Generation 1 novice knapper actually had the closest match, in terms of $\frac{Th}{B}$ and $\frac{T1}{L}$, to the base target of all handaxes knapped, with ratios of 0.310 and 0.072 respectively, but elected to pass on a form with ratios of 0.315 and 0.091. In Generation 2, the form chosen to pass on through the TC was remote both in terms of $\frac{Th}{B}$ and $\frac{T1}{L}$. The same issue occurs in the fourth iteration, where the single largest movement away from the previous target form occurred. The implication here is that other traits, such as shape attributes were dominant and considered more important to transmit than aspects of refinement. As with the previous experiments, the issue with Roe metrics (in isolation) is their inability to provide an impression of the shape of the whole handaxe, which would help determine the attributes that were being more faithfully transmitted.

To determine the effect of each generation's knapping on Roe refinement measures, a two-way *ANOVA* was conducted to test the hypothesis that each generation would perform as a cohesive group, producing an output that was distinct from the variation present amongst the sample as a whole i.e. from all generations. For all generations, *ANOVAs* test of 'between subject effects' revealed there was a significant difference between generations for both $\frac{Th}{B}$ (*p* = < 0.000) and $\frac{T1}{L}$ (*p* = 0.036), (see Appendix 6). Tukey's post-hoc test results for $\frac{Th}{B}$ showed specific significant differences between Generation 6 and all other generations. Other significant differences were between Generation 1 (*p* = 0.007) and Generation 2 (*p* = 0.002) and Generation 5. For $\frac{T1}{L}$, differences were less significant and occurred between Generations 1 (*p* = 0.45) and 2 (*p* = 0.57) and Generation 6 (Appendix 6). This, in tandem with Figure 8.5b, where each data-point is the mean ratio of both dependent variables for all handaxes, in each generation, indicated a broad generational movement (R^2 = 0.71, *p* = 0.035) away from the base target form; a trend likely related to the cumulative error associated with deficiency in levels of knapping skill. Figure 8.5a shows all knapped handaxes by generation and also highlights the dispersed performance of Generations 5 and 6, likely responsible for generating much of the significant inter-generational variation.

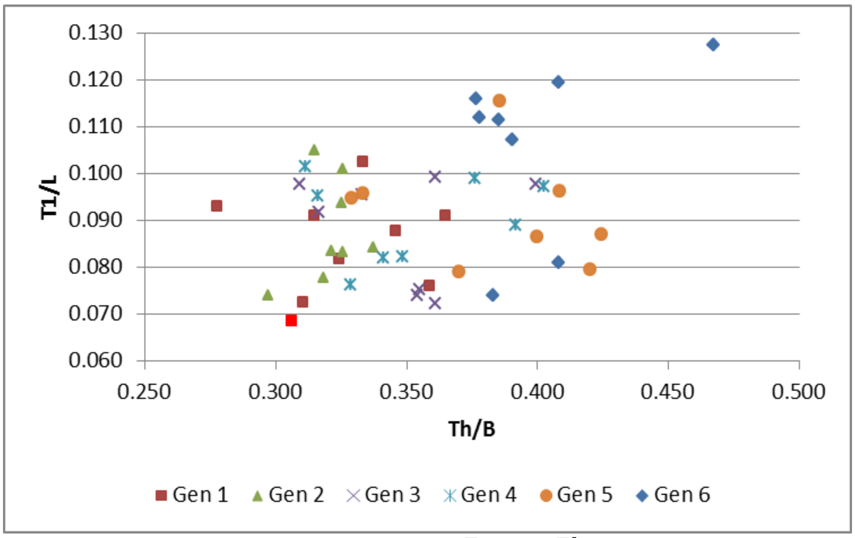


Figure 8.5a. Refinement measures $\frac{T1}{L}$ and $\frac{Th}{B}$ for all handaxes, plotted by generation. The red data-point marks the position of the base target form.

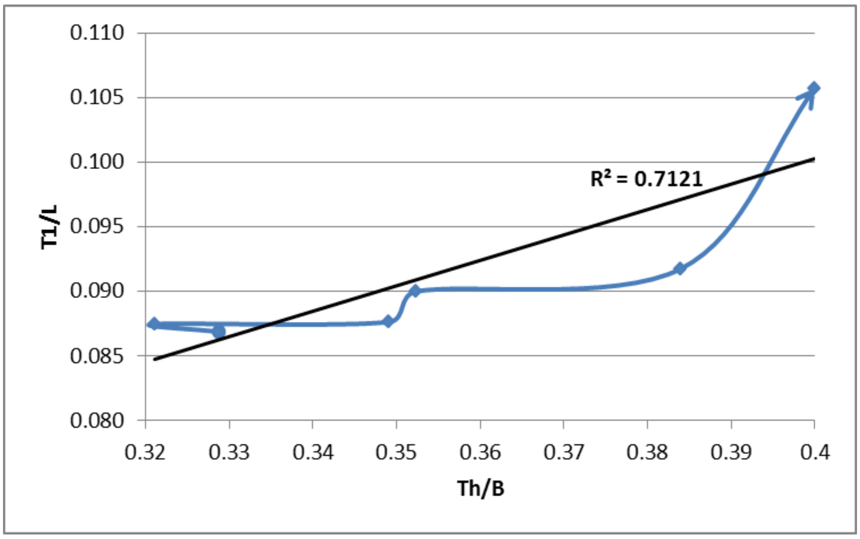


Figure 8.5b. Mean of refinement measures $\frac{T1}{L}$ and $\frac{Th}{B}$ for all handaxes, by generation (p = 0.035). The spot represents Generation 1 and the arrow, Generation 6.

8.3.3 Shape ratios

If the premise is that refinement, as discussed in 8.3.1 above, is submissive to other traits then identifying those traits should be possible from analysis of the Roe shape measures. The scatter showing $\frac{B}{L}$ against $\frac{L1}{L}$ and $\frac{B1}{B2}$ (Figure 8.6a) illustrates a broad spread of shape attribute achievement, in each case loosely centring on the base target form (shown as the red data-point in each spread of points). When compared with the initial scatter of $\frac{T1}{L}$ and $\frac{Th}{B}$ (Figure 8.3), where all refinement data-points (excepting two) were greater than that of the base target form, it provides further indication that refinement and shape measures were likely achieved and transmitted in different ways. This idea is also strengthened by the fact that for the chosen forms passed through the TC, no relationship of statistical significance was displayed between the knapping generations, for any of the Roe shape measures; *p values* for each attribute were as follows: $\frac{B}{L}$ = 0.132, $\frac{B1}{B2}$ = 0.447, $\frac{L1}{L}$ = 0.679 (Figure 8.6b), offering further contrast with how refinement measures were achieved.

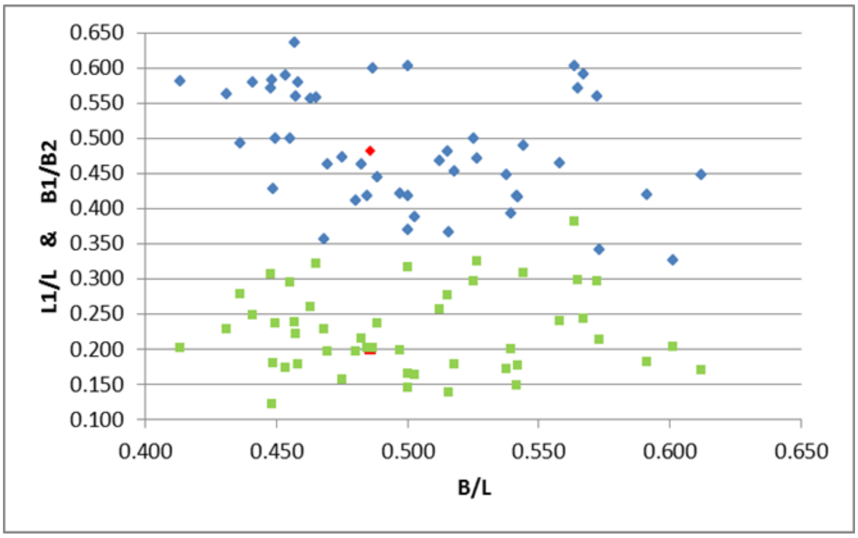


Figure 8.6a. Scatter of all handaxes plotting shape measures $\frac{L1}{L}$ and $\frac{B1}{B2}$ against $\frac{B}{L}$. The base target form is shown in red.

To gain insight on the interaction between the transmission of shape and refinement attributes required a closer examination of the chosen form data. For each generation after Generation 1, achievement of $\frac{L1}{L}$ varied extensively between minus 40.37% and plus 69.34% (Table 8.1). In all generations, this indicated an inconsistent management of where the widest point of the handaxe occurred. For all the shape ratios and refinement ratio $\frac{Th}{B}$, the biggest break in form came between generations 3 and 4. However, the difference between the two measures was that on an iterative basis, all shape ratios, especially $\frac{B}{L}$, began to re-converge on the ratios of the original target form (Figure 8.7 and Table 8.1). This raises the question of whether many-to-one interaction with an accomplished peer group was limiting the effect of novice copying error more for planform shape attributes than it was for refinement attributes. This being the case, the lack of significance displayed by the shape data may have been a reflection of the limitations of single dimension Roe measures, to capture the full nature of change, to the overall handaxe form. In keeping with the previous experiments, to test this idea, other measures will be explored in later sections of this chapter.

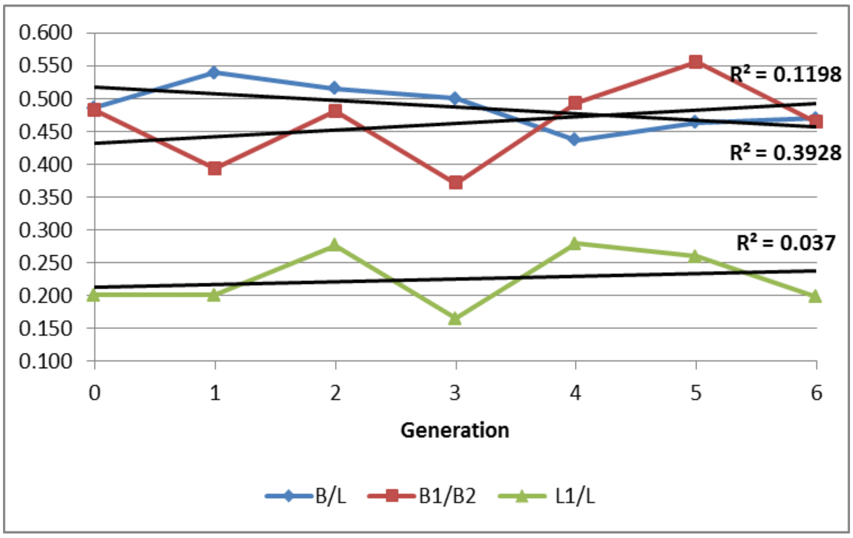


Figure 8.6b. Trajectory of Roe shape measures of the novice knapper, chosen forms by generation. The base target form is shown as Generation 0. There was no relationship of statistical significance.

Gen	B/L	% Var	B1/B2	% Var2	L1/L	% Var3
Base Tgt	0.486		0.482		0.200	-
1	0.539	11.05	0.393	-18.47	0.200	0.00
2	0.515	-4.46	0.481	22.19	0.276	38.04
3	0.500	-2.98	0.370	-22.92	0.165	-40.37
4	0.436	-12.73	0.493	33.10	0.279	69.34
5	0.463	6.10	0.556	12.70	0.259	-7.00
6	0.469	1.39	0.464	-16.52	0.197	-23.91

Table 8.1. The chosen form Roe shape ratios and generational variation.

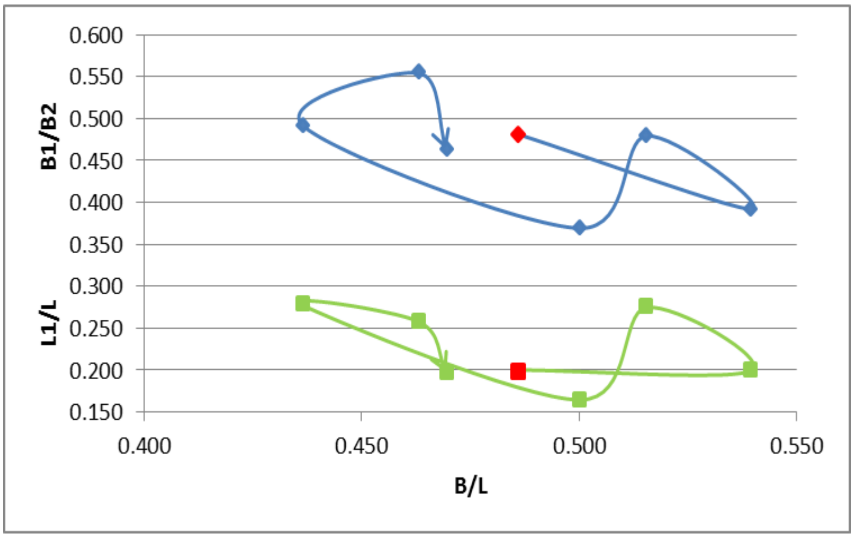


Figure 8.7. Path of the chosen forms by TC generation plotting Roe shape ratios $\frac{L1}{L}$ and $\frac{B1}{B2}$ against $\frac{B}{L}$. The base target form is marked in red.

To further explore how the many-to-one interaction scenario was affecting the transmission of shape attributes, the following analysis examined the achievement of form on a generational basis, as opposed to that achieved by the single knapper, where data showed limited significance (Figure 8.6b). The objective here was to help identify situations where the mean performance of all knappers in each generation, by attribute, may have performed differently from the chosen form of the novice knappers. If this was the case, then the chosen form could have carried with it significantly different attribute preferences compared to the overall generation. Two likely hypotheses for explaining this, either separately, or in combination, are as follows. Firstly, the copying error associated with the difficulty in managing multiple attributes simultaneously (as realised from Experiments 1 – 3), which would be more of an issue for the novice knappers, and/or secondly, the emergence of a group or generational norm, which was outweighing the importance of the target form for that generation. As with refinement measures, a two-way *ANOVA* was conducted to test the effect of generational knapping on each shape attribute (see Appendix 7 for a full breakdown of results). For $\frac{B}{L}$, for all knappers, the test of between-subjects effects revealed there was significant difference between the generations (p = < 0.000) but for $\frac{B1}{B2}$ and $\frac{L1}{L}$, no inter-generational differences were recognised as statistically significant. To determine which individual generations were producing variation within $\frac{B}{L}$, the multiple comparisons output of Tukey's post-hoc testing was used. It showed that significant differences occurred between Generation 2 and Generation 5 (p = < 0.000) and Generation 6 (p = 0.008), and also between Generations 5 and Generation 1 (p = 0.002), and Generation 6 and Generation 1 (p = 0.046). This indicated that where significant difference occurred within $\frac{B}{L}$, it was between the first two and last two generations of the TC; likely a result of a gradual but cumulative form change, over multiple generations of copying.

To view this change in context, Figure 8.8 looks at the mean achievement of each of the shape ratios, by generation. As with the *ANOVA*, change for $\frac{B1}{B2}$ and $\frac{L1}{L}$ was not significant, with low R^2 values and p values of 0.26 and 0.53 respectively. However, the downward trend of $\frac{B}{L}$ resulting in narrower handaxes relative to length was a result of inter-generational movement (R^2 = 0.796), as the TC progressed through its knapping iterations, was also statistically significant (p = 0.017). When the mean generational $\frac{B}{L}$ ratio is compared with that of the novices chosen form, the respective performance between Generation 1(G1) and Generation 6 (G6) is very similar: mean G1 = 0.535, chosen G1 = 0.539; mean G6 = 0.476, chosen G6 = 0.469. In this scenario, although variation in $\frac{B1}{B2}$ and $\frac{L1}{L}$ was more random in nature, the interpretation for $\frac{B}{L}$ is that the many-to-one instructional TCP was creating a situation where the novice knappers were producing handaxes in line with those produced by each generation as a whole (and vice-versa).

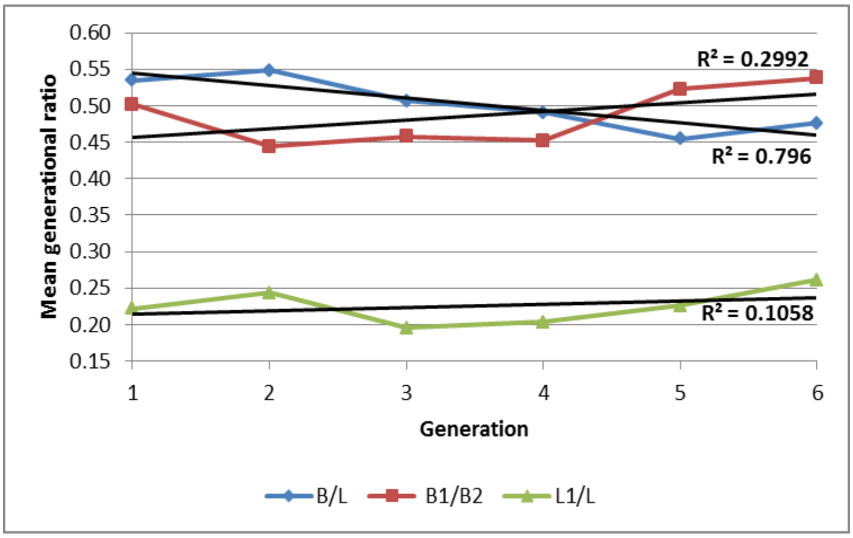


Figure 8.8.Comparative mean performance of attribute ratio achievement for all knappers, by generation. Only $\frac{B}{L}$ was significant (p = 0.017).

8.4 Measures of taper and 3D Euclidean distance

Roe's use of weight as a basic or traditional measure of 3D volume possessed the potential to add depth to the information provided by the ratio based analysis, with regard to the effect of reduction on the mass of the handaxe (as in Experiment 3). For Experiment 4, Figure 8.9 shows there was a loss of volume. However, $R^2 = 0.564$ and $p = 0.052$ meant significance was limited.

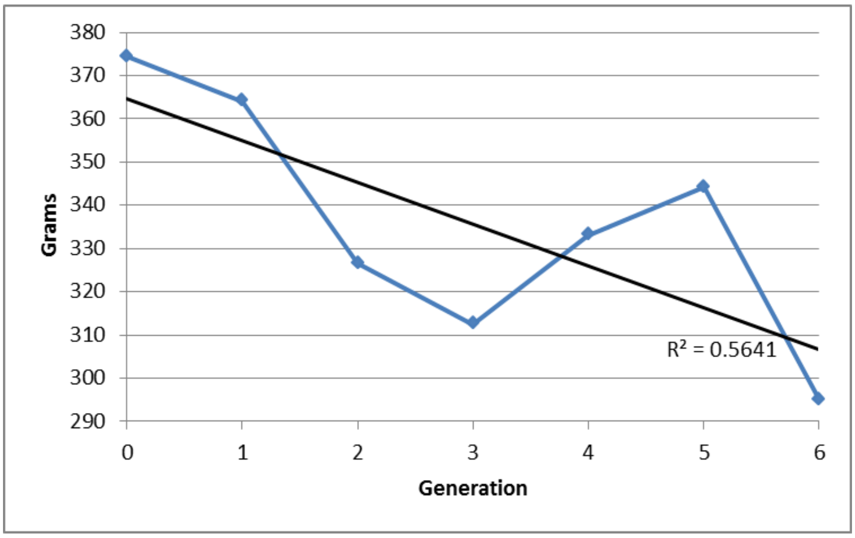


Figure 8.9. Trajectory of handaxe weight, for the novice chosen forms, through the TC of Experiment 4 (p = 0.052).

Despite convergence of the chosen form Roe shape ratios on those of the base target form (Figures 8.7 and 8.6b), the extent to which form was actually evolving was not effectively revealed, even when viewed in combination with the handaxe weight figures (Figure 8.9). To aid in that process, Figure 8.10a plotted taper (adjusted for length) against 3D Euclidean distance from the base target form, for the chosen form of each generation in the TC. Whilst the degree of taper increased and decreased randomly in each alternate iteration (except Generation 4), Euclidean distance became progressively larger indicating a directional size move away from not only the base target form, but also each generational target form. This was a significant relationship (*p* = 0.00559) with $R^2 = 0.812$ indicating the causal strength of the interaction between generational knapping and the move away from the dimensional metrics of the original target form (Figure 8.10b). These characteristics suggest a generational change not only in size but also shape, something not detectable using weight in isolation, due to the irregular nature of handaxe shape. The only exception to iterational movement was between Generations 2 and 3 where Euclidean distance was maintained (12.08mm and 11.40mm respectively, Figure 8.10a) despite the change in degree of taper from 0.409 to 0.518 and a loss of weight. This relative degree of 3D stability may be linked to the fact that Generation 3, compared to all other generations in a two-way *ANOVA*, failed to demonstrate any significant difference, for shape or refinement ratios (Appendices 5 & 6).

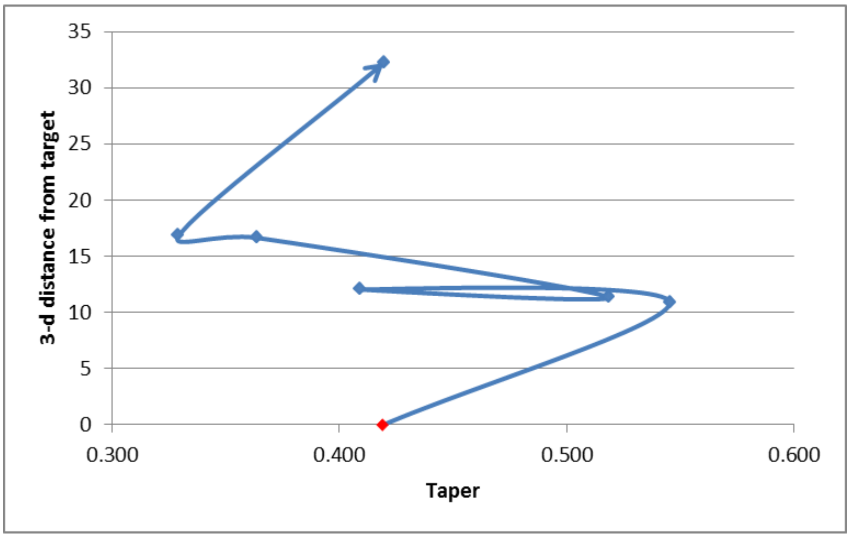


Figure 8.10a. Path of the chosen forms as they passed through the TC, plotted using taper and 3D Euclidean distance from base target form.

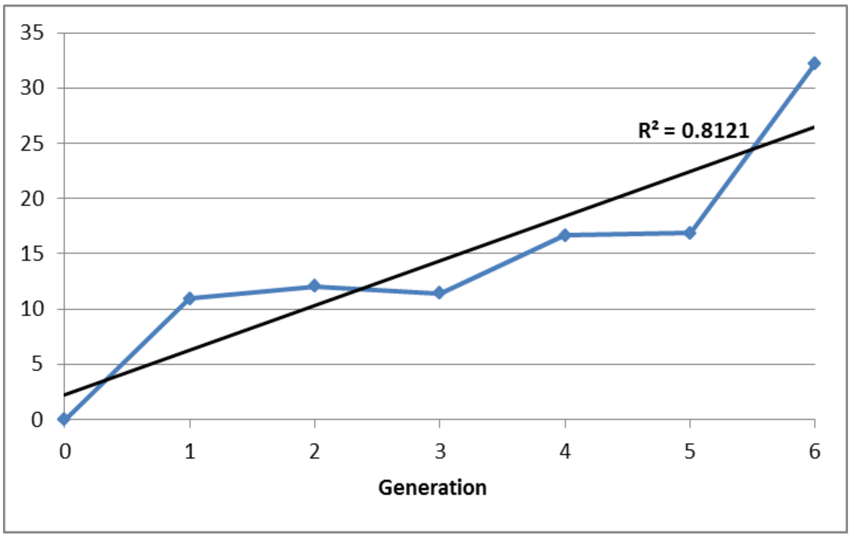


Figure 8.10b. Trajectory of the chosen form from the base target form, showing the relationship between Euclidean distance and knapping generation (p = 0.00559).

To ascertain if there was a link between achievement of form as measured by Euclidean distance and the inter-generational differences identified by the Roe shape ratios, 3D distance from base target form and taper for each handaxe, by generation (Figure 8.11), was also tested using two-way *ANOVA*. For Euclidean distance, there was significant interaction at the level of all generations (p = 0.020), with specific difference in achievement between Generation 3 and Generation 6 (p = 0.041). For taper, there was also significant interaction at the level of all generations (p = 0.010), with specific differences between Generation 2 and Generation 5 (p = 0.018) and Generation 6 (p = 0.022). This variation is reflected in the closeness of the chosen form of Generation 2 to the base target form, when compared to other generations (Figure 8.10a). It also repeats the tendency for Generation 2 to produce significant differences more regularly than other generations (see 8.3.2 & 8.3.3).

Although significant variation had been identified by two different measurement techniques (linear regression and *ANOVA*), there was still an inability to identify whether variation in weight, shape and refinement measures was actually making handaxe size/shape larger or smaller. This is exemplified by Figure 8.12, where the degrees of taper and $\frac{L1}{L}$ of Generation 6 had returned to the same proportion and levels as that of the base target form, indicating limited long-term change in form. The reality was, however, somewhat different. Initial indication of this was provided by the downward trends of linear measures, length and breadth (Figure 8.2), but the scale of variation was more effectively illustrated by the *ADVA* of the base target form and chosen form of Generation 6, which were 103.38cm² and 69.28cm² respectively (Table 8.2). This difference was, to an extent, identified by the Euclidean distance measure of 32.25mm from base target form (Figure 8.10a), but as with previous experiments, it was still unclear whether that measure represented an increase or decrease in size.

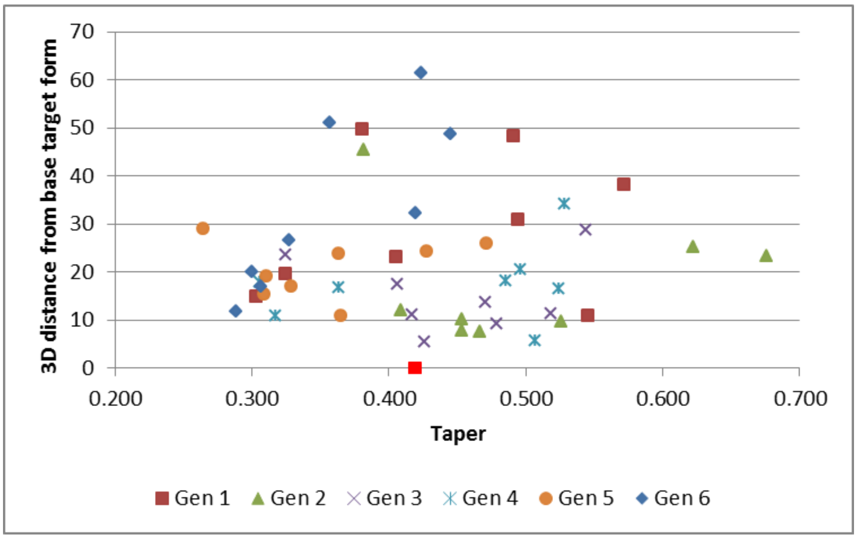


Figure 8.11. All handaxes by generation, using measures of taper and 3D Euclidean distance to identify group performance. The red data-point is the base target form.

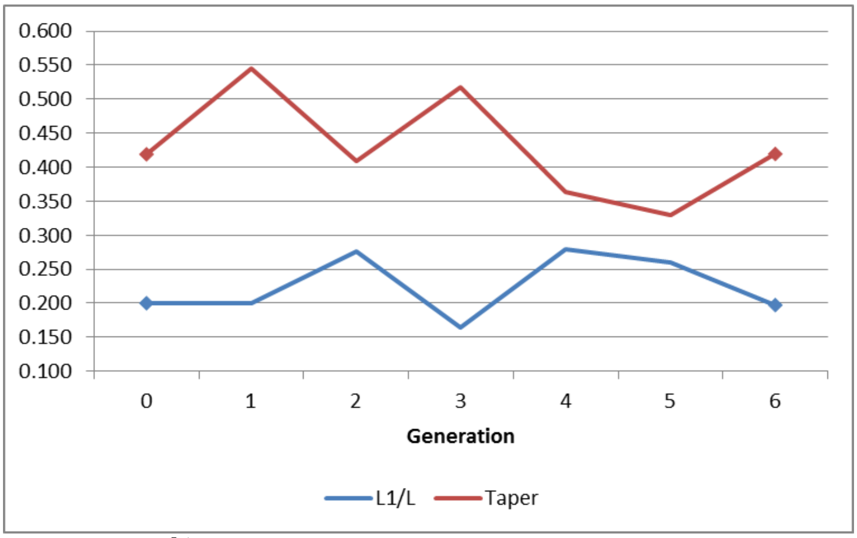


Figure 8.12. $\frac{L1}{L}$ and taper showing Generation 6 shape returned to the proportions of the base target form; not efficient indicators of change due to lack of size information

8.5 Area based measures of refinement and shape, derived from ImageJ

8.5.1 Edge and planform area

To provide the measure of total handaxe size missing from the evidence presented by Roe's ratios and the geometric data, planform *ADVA* was used. On the basis of that data alone, there was indication that nascent generational differences were forming in Generations 2, 3 and 5. Figure 8.13 shows the area ranges (cm²) of all handaxes knapped in each generation, with the target form for that generation highlighted in red. The base target form handaxe area of 103.38cm² fell to 93.18cm² in the first generation. In Generation 2, it fell again to 85.11cm², furthering the idea that the initial management of overall handaxe size was strongly linked to the level of skill possessed by the knappers. Against a null hypothesis that the spread of variation in handaxe area was even and not affected by the knapping generation, *ANOVA* was run, where $p = 0.019$ and the *F value* at 3.06 was greater than *F critical* of 2.43, showing variation between all groups was significant and a product of the knapping generations of the TC. Tukey's post-hoc testing revealed that the statistically significant differences occurred between Generation 6 and Generation 2 ($p = 0.011$) and Generation 3 ($p = 0.052$); so again, it seemed variation and the possible occurrence of a norm, differing from other generations, was occurring in these two generations.

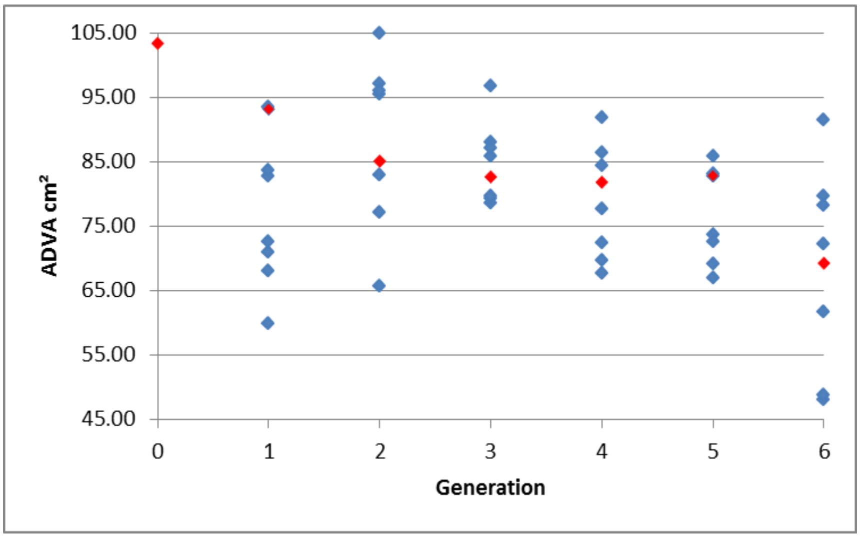


Figure 8.13. Handaxe area in cm² for each knapper, showing the range in size, by generation. The base target form is marked in red as are the handaxes chosen to be the target form for the subsequent generations.

A linear regression fitted to the chosen form of the Experiment 4 TCP (Figure 8.14), further emphasised the link between loss of handaxe size and inter-generational knapping performance. This significant downward trend (p = 0.0032) was initiated by the shrinkage seen in the first two generations and was further influenced by what was perhaps an outlier performance in Generation 6. This aside, there was a stabilisation of *ADVA* in generations 2, 3 ,4 and 5 that could be attributed to the effect of the many-to-one interaction experienced in the accomplished peer group scenario. The photographs of each chosen form handaxe in the Experiment 4 TC also illustrate this point (see Appendix 8).

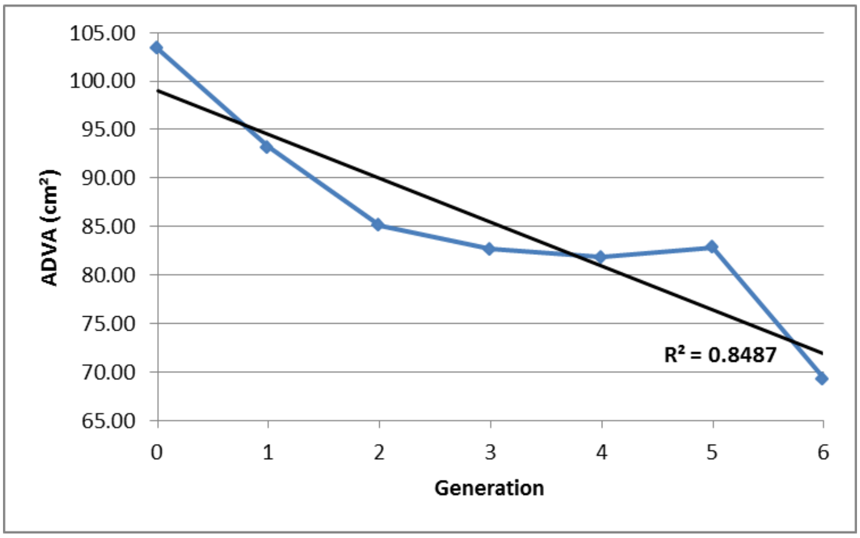


Figure 8.14. Trajectory of chosen form *ADVA* as it passed through the TC (p = 0.0032).

To gain an idea of handaxe shape related to pointedness, analysis was performed on area based measure *ADVA*, with Roe's measure of pointedness, $\frac{L1}{L}$. As noted, there were significant intergenerational effects for *ADVA* (p = 0.019) and specific differences between Generation 6 and Generations 2 and 3, but for $\frac{L1}{L}$ there was no significant intergenerational difference at all (p = 0.218). This suggested all knappers, in all generations, had difficulty with managing consistency of $\frac{L1}{L}$, or more specifically, the measure that defined the fundamental pointedness of the handaxe. Figure 8.15 plots *ADVA* against the $\frac{L1}{L}$ shape measure for all handaxes, and confirmed that simultaneous maintenance of handaxe size and pointedness was a problematic relationship to maintain.

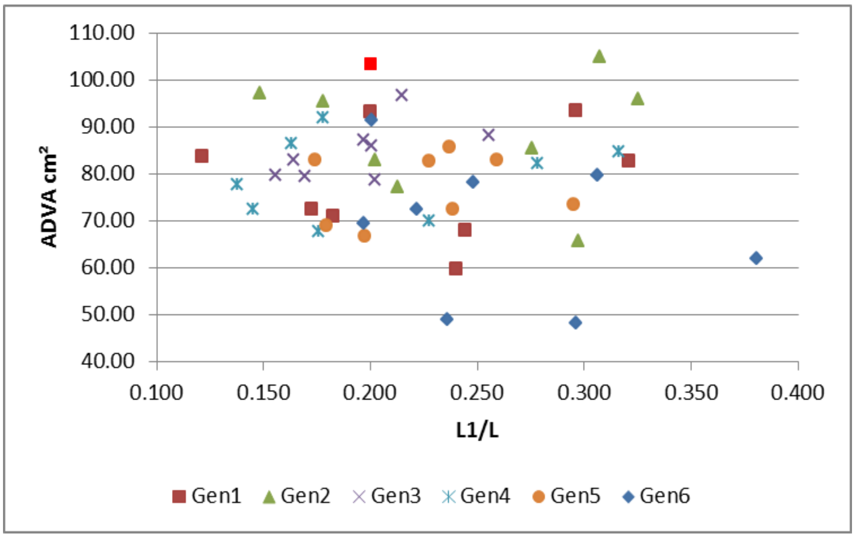


Figure 8.15. A scatter of all handaxes, by generation, where area in cm² was plotted against shape measure $\frac{L1}{L}$.

As with Experiments 2 and 3, instead of using $\frac{AEA}{ADVA}$ as a refinement measure for all handaxes, *AEA* was replaced by Roe's thickness measure '*Th*' (see methodology section 3.5.8.2 for details). The resultant data for the chosen forms passed through the TC by the novice knappers, displayed significant likelihood that the variation or interaction between increasing handaxe thickness and decreasing handaxe area was linked to their knapping performance. On an iterational basis, this produced a linear trend line where $R^2 = 0.7272$ and p = 0.015 (Figure 8.16a). This strong relationship clearly linked transmission of form to the production of smaller, thicker handaxes. Examining the same data at the group level by running a one-way *ANOVA,* also showed a significant difference between generational reproduction of the $\frac{Th}{\sqrt{ADVA}}$ attribute (p = 0.05). On an inter-generational basis, Tukey's post-hoc test revealed significant variation existed between Generation 1 and Generation 6 (p = 0.033), and moderate significant difference between Generation 2 and Generation 6 (p = 0.088). The range of variation by generation, for all handaxes knapped, based on $\frac{Th}{\sqrt{ADVA}}$, is presented in Figure 8.16b. The variation highlighted by Tukey's post-hoc testing was effectively illustrated by the dispersed range of $\frac{Th}{\sqrt{ADVA}}$ for Generation 6, compared to the tighter and more consistent clusters in all other generations.

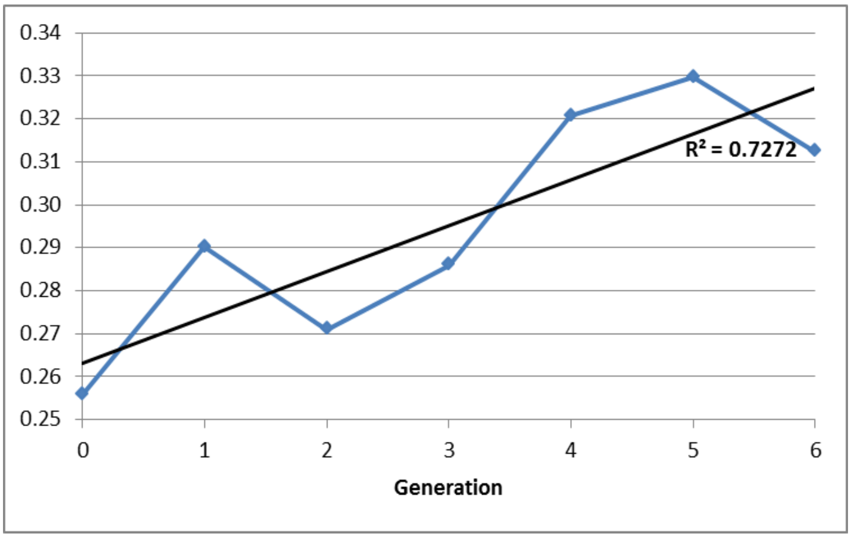


Figure 8.16a. Trajectory of the 'mixed' refinement measure $\frac{Th}{\sqrt{ADVA}}$ as the chosen form was passed through the TC (p = 0.015).

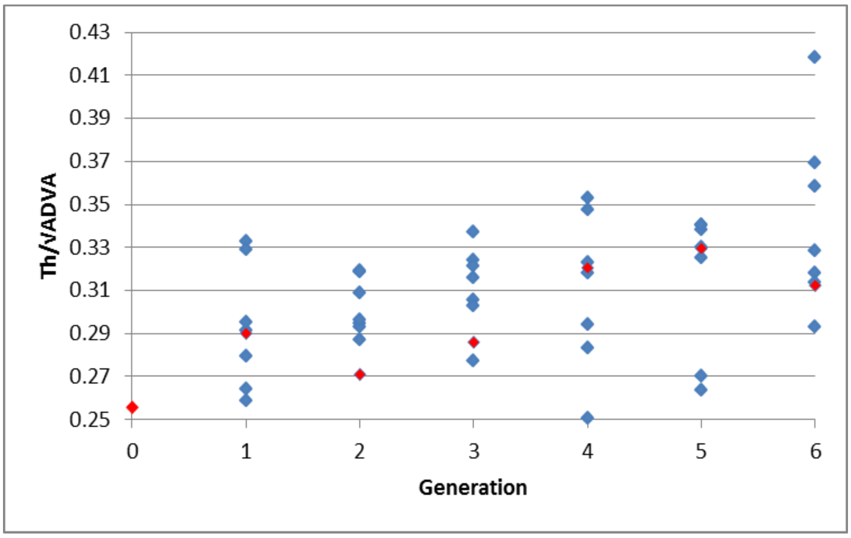


Figure 8.16b. Refinement measure $\frac{Th}{\sqrt{ADVA}}$ for each handaxe, by generation. Base target form and subsequent chosen forms are marked in red.

When the above results are viewed in conjunction with Figure 8.14 and 8.13, where the total planform area, as a single measure, appeared to have stabilised in generations 2, 3, 4 and 5, it further supports the shift towards the evolution of smaller, slightly thicker handaxes; a directional trend led by the chosen forms and likely mediated by knapping skill. This idea can be explored by viewing area data in conjunction with Roe's refinement measures $\frac{Th}{B}$ and $\frac{T1}{L}$. The $\frac{Th}{\sqrt{ADVA}}$ ratio presented the same basic trajectory as the Roe refinement ratios (Figure 8.17), indicating the existence of a relationship between changes in handaxe form and the generational movement of each novice knapper (and their group) within the TC. The three sets of data were all significant ($\frac{Th}{B}$, *p* = 0.026; $\frac{T1}{L}$, *p* = 0.041; $\frac{Th}{\sqrt{ADVA}}$, *p* = 0.015), and in the majority of cases, demonstrated only small iterational increases in thickness, relative to size. The increase indicated by Figures 8.16 (a & b) and 8.13 was more likely the effect of the larger shift in $\frac{Th}{B}$ between generation 3 and 4, as already highlighted in Figure 8.4 (a & b). This was produced by a skill-related change, specific to one generation. Further, it was the product of a relatively small decrease in *ADVA* accompanied by a relatively small increase in thickness (*Th*). The combined result of both changes, perhaps better illustrated by the more inclusive $\frac{Th}{\sqrt{ADVA}}$ adjusted area measure, was to alter the relative dimensions of the handaxe enough to increase the refinement ratios in one handaxe, i.e. creating a thicker smaller form which, in turn, was a pattern reproduced by the subsequent knappers. The overall effect of this trend was to alter the refinement trajectory of the entire TC (see Figure 8.17 to compare all refinement measures).

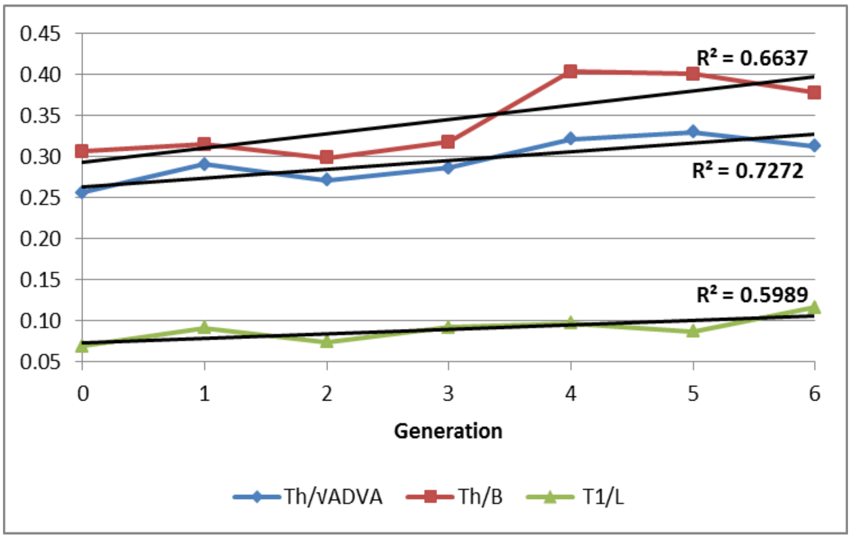


Figure 8.17. Refinement measures $\frac{Th}{B}$ (p = 0.026), $\frac{T1}{L}$ (0.041) and $\frac{Th}{\sqrt{ADVA}}$ (0.015) for each chosen from, by generation; showing basic agreement between measures in the significant trajectory of the TC.

8.5.2 Residual cortex area

The basis of Roe's evaluation system was metric, making it reliant on straight line measures between predefined points. The hypothesis behind using residual cortex area was that it could provide an alternative or supplementary method to more effectively gauge the achievement of handaxe refinement. As a tool for measuring the transmission of handaxe refinement, levels of residual cortex, as a percentage of both dorsal and ventral faces, produced very erratic results. Figure 8.18 shows those percentages plotted with the refinement measures already discussed above. Ventral cortex behaved in a similar way to other attributes, with low levels of variation and relatively accurate trait reproduction. Levels of residual dorsal face cortex, however, appear completely incidental and in all cases, with the exception of Generation 6, cover areas of more than 25% of the dorsal face. The fact that these exceptionally high levels began in Generation 1 and then continued to increase was an indication that, as with previous experiments, accurate reproduction of cortex patterns was either incidental and a product of insufficient skill levels to manage multiple traits simultaneously, or, it was of tertiary importance to achieving accurate reproduction and transmission of other refinement and/or shape traits. Low R^2 values of 0.003 and 0.03 for % dorsal cortex and % ventral cortex respectively, failed to overturn a null hypothesis that 'levels of residual cortex were directly linked to inter-generational knapping performance as a primary goal'. This suggests the incidental nature of the attribute and, in this context, highlights that when levels of skill are at a level lower than that of a very experienced knapper, residual cortex is a less effective measure of refinement than, for example $\frac{Th}{\sqrt{ADVA}}$.

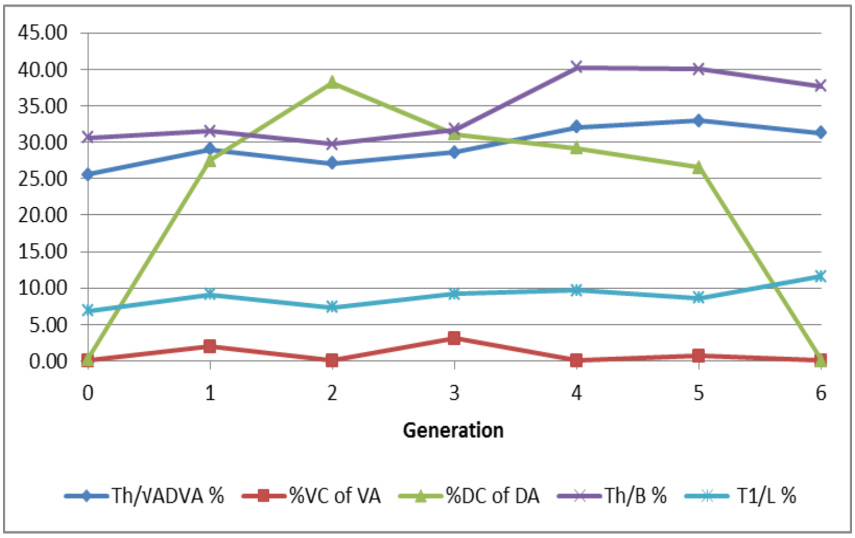


Figure 8.18. Residual cortex area as a percentage of each handaxe face, for the chosen forms, by generation. Other refinement measures are plotted for comparison.

8.5.3 Combining handaxe shape measures

Despite the ineffective nature of residual cortex as a diagnostic attribute measure (in this context), combinations of traditional Roe ratios, new metric approaches and digitally produced measures, proved useful in capturing form change as a result of inter-generational copying. When handaxe size (cm^2) was regarded as a component of shape measure, the following effects of the Experiment 4 TCP were noted. The largest changes in size or handaxe area occurred in Generation 1 and Generation 6, with iterational falls of 9.87% and 16.38% respectively. Both decreases, especially that of knapper 6, were likely results of insufficient knapping skill (Generation 6 could be described as an outlier). The initial drop from the 103.38cm^2 area of the base target form was, however, especially significant, as it immediately redefined the overall size of the target form for the entire TC (Table 8.2). Despite this change, the overall shape of the handaxe as it passed through the TC remained relatively unchanged, and is perhaps best illustrated by Figure 8.19, where the $\frac{B}{L}$ and $\frac{L1}{L}$ points, when joined, both produced shallow lines to maintain the essentially pointed nature of the handaxe. Taper, adjusted for length, tended to fluctuate randomly (expanding and contracting alternately on an iterative basis), and Euclidean 3D distance from base target form, after it had recovered from the initial Generation 1 movement (and excluding Generation 6), also remained relatively stable. Considering all shape measures under this TCP, the overall effect of many-to-one instruction from an accomplished peer group, was to produce a handaxe that was smaller than the base target form, but proportionately (in plan-view), very similar.

Generation	ADVA (cm^2)	ADVA % i change	B/L	L1/L	Taper	3D distance (mm)
Base tgt	103.38	0.00	0.486	0.200	0.419	0.00
1	93.18	-9.87	0.539	0.200	0.545	10.95
2	85.11	-8.66	0.515	0.276	0.409	12.08
3	82.67	-2.87	0.500	0.165	0.518	11.40
4	81.84	-1.00	0.436	0.279	0.364	16.67
5	82.86	1.25	0.463	0.259	0.329	16.88
6	69.28	-16.38	0.469	0.197	0.420	32.25

Table 8.2. Combining handaxe shape measures to gauge form change by generation.

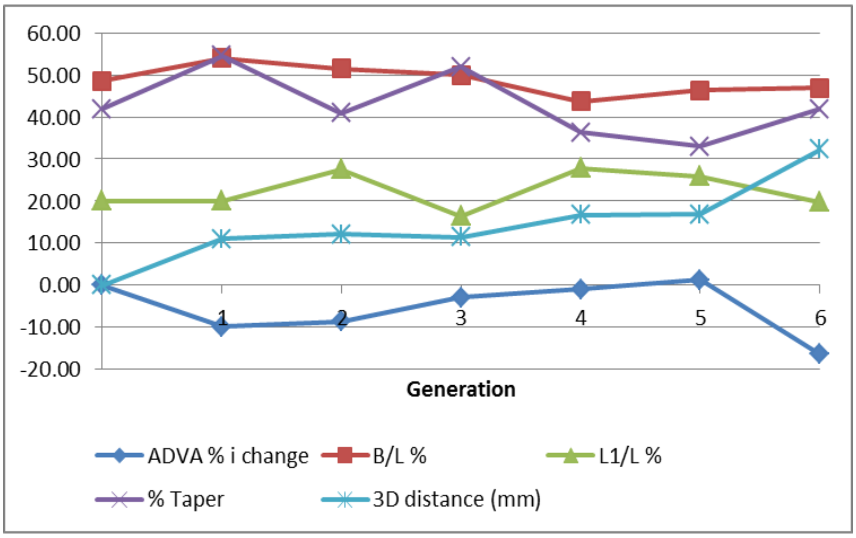


Figure 8.19. Combining shape measures to plot TC trajectory and form change by generation.

8.6 Handaxe symmetry

Consistent achievement of form was also apparent with regard to handaxe symmetry. ‘Very high’ or ‘virtually perfect’ levels of symmetry were achieved by 42 out of 48 (87.5%) of the handaxes knapped by the 6 generations of Experiment 4 (Figure 8.20). This indicated the ease with which this attribute was transmitted, in all handaxes produced by all knappers, not solely the handaxes chosen to pass through the TC as subsequent target forms (highlighted in red). Each of those forms, with the exception of Generation 5, although not as symmetrical as the base target form (with a *VAI* of 1.51), still maintained 'Very high' levels of symmetry throughout the duration of the TC. Exploring how each generation performed as a discrete group, a one-way *ANOVA* produced p = 0.055 and an *F value* of 2.37, that failed to pass the *F critical* of 2.44. Tukey's post-hoc testing also revealed no significant specific inter-generational differences. The consistency with which all knappers reproduced and transmitted symmetry (measured by the *VAI*) was verified by the failure to overturn the null hypothesis, that there was no variation in the *VAI* between any generations of the TC.

The consistency of symmetrical form was illustrated further by Figure 8.21 and the tightly compressed nature of the majority of data points. In this context, the homogenous standard of reproduction and transmission of symmetry was something that pervaded all knapping. This was particularly true in the case of Generation 6 and Generation 1, who tended to reproduce and transmit most other traits poorly and on a disparate basis. Symmetry was not an attribute that could be seen as integral to the formation of variation significant enough, to produce group norms with the potential to lead to the evolution of new asymmetrical forms, different from those of the founder or parent generations.

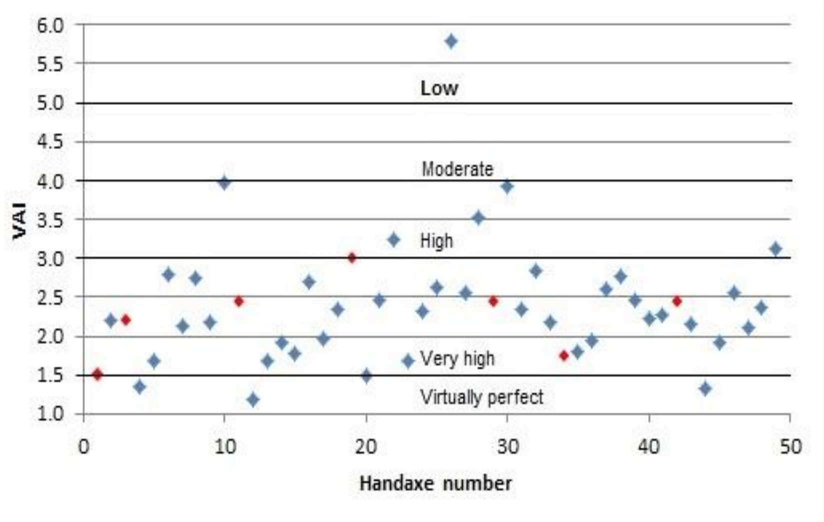


Figure 8.20. Scatter plotting level of handaxe symmetry (*VAI*) for all handaxes. The base target form and subsequent chosen forms are highlighted in red.

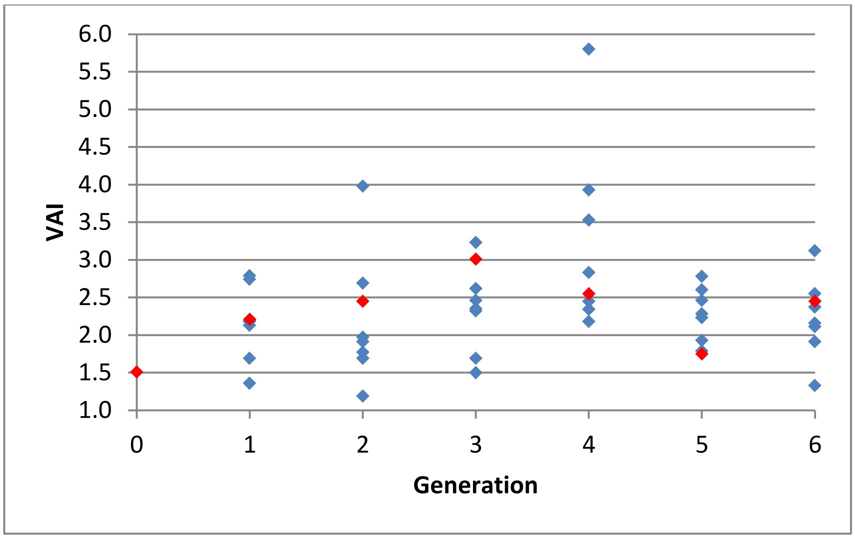


Figure 8.21. Handaxe symmetry (*VAI*) for all handaxes, showing the range of *VAI* by generation. The base target form and subsequent chosen forms are highlighted in red.

The strength of symmetry as a trait was further highlighted by examining the relationship between the *VAI* of the target form of each generation and the *VAI* elected to pass on. Each of those forms is highlighted by the red markers in Figure 8.21. For example, the target form for Generation 2 is the red marker present in Generation 1, and the *VAI* of the handaxe Generation 2 elected to pass on as the target form for the next generation (3 in this case), is indicated by the red marker present in the Generation 2 column, and so on, through the transmission chain (Figure 8.21). For Generations 3, 4 and 5, a form with a higher degree of symmetry (marked by a lower *VAI*) than that of the target form of each respective generation, was transmitted to the next generation. The constancy and strength of symmetry as a trait was further illustrated when, in Generation 6, the *VAI* did increase, it was only to 2.45, which is still within the 'Very high' symmetry classification defined by Flip Test (Hardaker & Dunn, 2005). So, even when the transmission of other traits weakened substantially, in Generation 6 for example (see Table 8.2), 'very high' levels of symmetry were still maintained, repeatedly indicating its dominant nature as a trait.

To further examine how symmetry co-occurred with other attributes when subject to accomplished peer group interaction but for each generation as a whole, combinations of mixed measurement shape and refinement attributes were analysed by using scatter plots and running two-way *ANOVAs*. To refine handaxe size as a measure, handaxe shape, as defined by $\frac{L1}{L}$, was plotted against *VAI* to test the hypothesis that symmetry would also take precedence over degree of pointedness. Figure 8.22 showed that for *VAI*, the overall level of symmetry was maintained within the 'very high' boundaries defined by Flip Test and results from the *ANOVA* test of 'between-subject effects' revealed that there was no significant difference between any generations (for all handaxes) for either *VAI* (p = 0.55) or $\frac{L1}{L}$ (p = 0.218), pointing to quite a standardized group or inter-generational output. However, when looking at attribute achievement and selection in more detail, Figure 8.22 also showed that, although *VAI* scores were predominantly 'very high', there was a large degree of movement between the target form and chosen form of each generation for $\frac{L1}{L}$. For example, the target form for Generation 3 had a $\frac{L1}{L}$ ratio of 0.276, but the form chosen to pass on was 0.165. Generation 4 failed to replicate that, and passed on a ratio of 0.279. It was not until Generation 5 that $\frac{L1}{L}$ was accurately transmitted with a ratio of 0.259. That was short lived and in Generation 6, it was weakly transmitted again and became 0.197. This suggested that as a trait, handaxe shape (i.e. its level of pointedness as defined by $\frac{L1}{L}$) was difficult to manage, reproduce and transmit and again, it remained of secondary importance, behind symmetry.

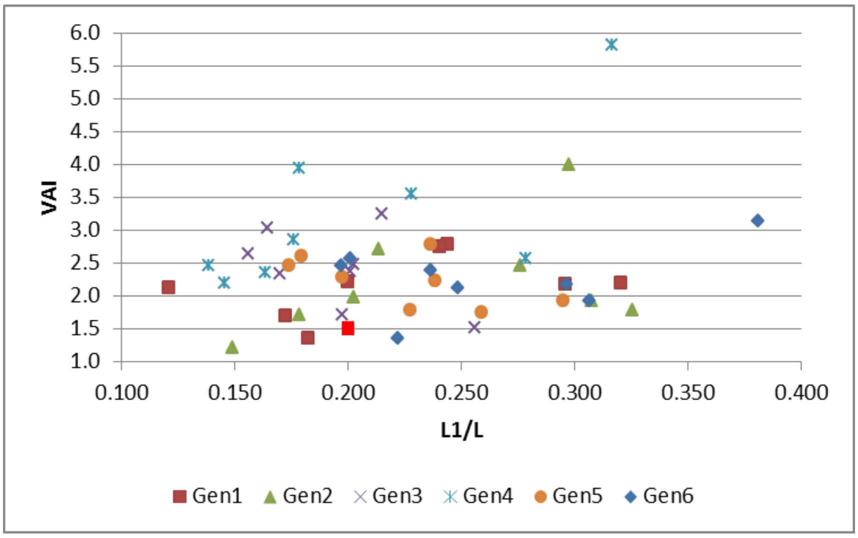


Figure 8.22. A scatter plotting handaxe symmetry against shape measure $\frac{L1}{L}$, by generation.

Handaxe refinement (measured by $\frac{Th}{\sqrt{ADVA}}$), also plotted against *VAI* and analysed by a one-way *ANOVA*, showed that difference in total inter-generational $\frac{Th}{\sqrt{ADVA}}$ was significant (p = 0.05), with specific significant differences occurring between Generation 1 and Generation 6 (p = 0.033), and a moderate significant difference between Generation 2 and Generation 6 (p = 0.088) (Appendix 9). Figure 8.23 shows, to some extent, that the significant inter-generational differences (Generation 1 and 2) can be seen in the clustering of points. However, in the majority of cases distribution was as dispersed as it was for shape measure $\frac{L1}{L}$. Strength of $\frac{Th}{\sqrt{ADVA}}$ transmission for the chosen forms was also relatively weak, increasing from a base target form ratio of 0.256, to 0.330 and 0.312 in Generations 5 and 6 respectively, whilst *VAI* remained consistently within the confines of 'very high' levels of symmetry (Figure 8.24). Viewed in relation to other measures, symmetry appeared as the trait that, although subject to variation, still managed to be consistently replicated with 'very high' levels of fidelity. In terms of co-occurrence, it was transmitted more effectively than size (*ADVA*), refinement ($\frac{Th}{\sqrt{ADVA}}$) and shape ($\frac{L1}{L}$).

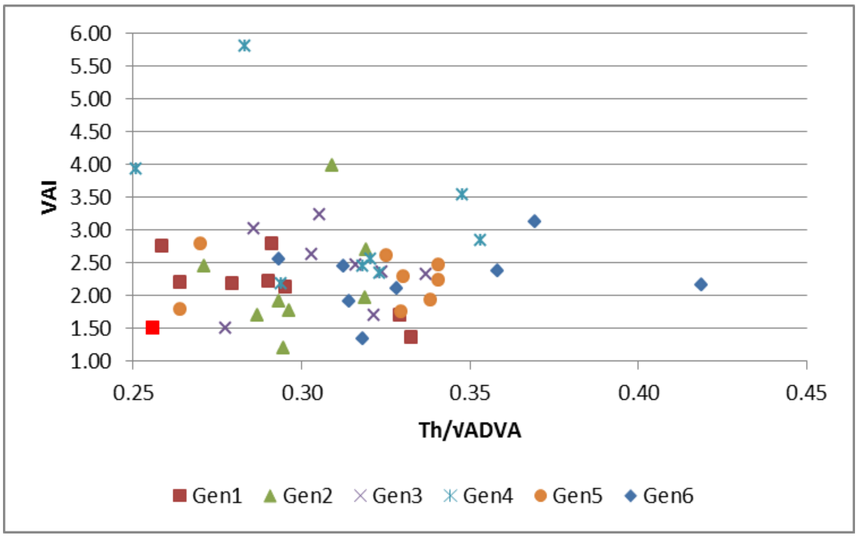


Figure 8.23. A scatter plotting handaxe symmetry against refinement measure $\frac{Th}{\sqrt{ADVA}}$, by generation. Compactness and clustering of data points shows a consistency of generational reproduction for both traits.

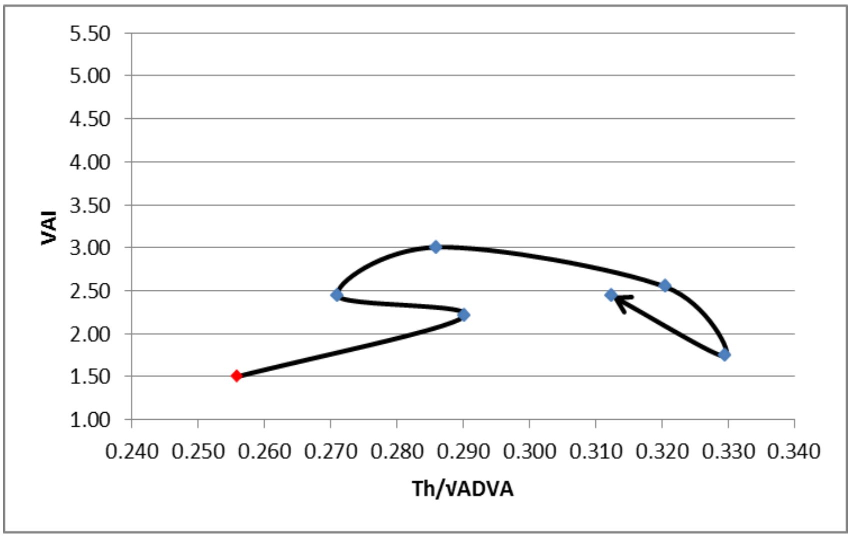


Figure 8.24. Transmission chain path of handaxe symmetry (*VAI*) and refinement measured by the $\frac{Th}{\sqrt{ADVA}}$ ratio, for the chosen forms.

8.7 Conclusion

Experiment 4, subject to a TCP of many-to-one instruction from an accomplished peer group, showed clear links between the inter-generational progress of the TC and the change in chosen or target handaxe form, as it was transmitted through the TC. For the Roe ratios, linear regression demonstrated the relationship was most meaningful for the refinement measures, primarily $\frac{Th}{B}$. For the shape ratios, it was not until the introduction of a more inclusive area based measure, derived from imaging software that an inclusive picture of form change, with statistical significance emerged. The trend towards a form that became progressively thicker and smaller was verified by $\frac{Th}{\sqrt{ADVA}}$ measures, while $\frac{L1}{L}$ demonstrated the handaxes were also becoming less pointed. Use of *ANOVA* revealed indications of inter-generational differences, often forming away from the attribute patterns of the target form for each group. This became apparent in Generation 2, from the analysis based solely on Roe measures, when $\frac{B1}{B2}$ (taper) and $\frac{B}{L}$ started clustering and were being more accurately transmitted than $\frac{L1}{L}$.

To better examine the effect that inter-generational changes were having on form, area based measures of size, used in conjunction with handaxe symmetry, shape and refinement measures showed that of all traits, planform symmetry was reproduced and transmitted the most consistently, within and throughout the generations of the TC. Although Roe ratios often indicated relatively small changes in form, the reality of the situation was that handaxe size had changed considerably. After just two generations of copying, the chosen form was 17.67% smaller than the base target form, but throughout this period of change in size, handaxe symmetry had been maintained and continued to be transmitted at a ‘very high’ level, in all generations. This appeared to be the core trait around which variation in other traits was accommodated, so, in this respect, overall handaxe form or the basic physical construct of the tool was maintained, but variation occurred within that form on an intra and inter-generational basis.

Variation throughout the TC was more likely dictated by the non-directional nature of differences in the levels of knapping skill than the deliberate formation of generational norms or the cumulative operation of purely random factors, such as perceptual limitation. At the macro level, the implication of this scenario could be the occurrence of regional or temporal variation in handaxe form, operating within a broad overall tool form. If the subsequent transmission of the new target form followed a similar trajectory to the TC of Experiment 4, then significant form change would, however, be short lived before variation in skill level in each cultural grouping caused an interruption in previous cumulative form change.

Chapter 9.

A comparative study and discussion of transmission biases and their effect on Acheulean handaxe form

9.1 Introduction

Experiment 2 (Chapter 6) focused on uninstructed end-state copying, a situation where there was no socially created or enforced bias to effect the achievement and transmission of handaxe form. This TC was conducted to provide a base line or comparative point from which to evaluate the more active or direct types of transmission bias explored by the rest of the programme. Experiment 3 (Chapter 7) focused on one-to-one expert instruction with knapping guidance provided by a cultural parent. Experiment 4 (Chapter 8) focused on accomplished peer group instruction, where knapping was conducted in an environment where guidance was provided to the intermediate level knapper, on a many-to-one basis, by peers who possessed higher levels of skill. Here, focus was on the group in the cultural transmission process and gauging the effect it would have on the achievement and transmission of form, by each of the less skilled, intermediate level knappers.

The purpose of this chapter is to examine the experimentally created transmission biases described above, and compare and evaluate their respective effects on handaxe form over multiple generations of copying. Linkage with the issues discussed in Chapter 5, explaining long periods of stasis in handaxe production or occurrences of short lived temporal or spatial variation within a standardised tool form, will be addressed further by assessing the differing effects that each of the experimental TCPs had on handaxe form, albeit on a micro-scale level. There will also be a comparison and discussion of the experimentally generated data with that produced from archaeological assemblages of the Middle Pleistocene. The basic or overarching null hypothesis for all comparisons is that there was no significant variation between the different TCPs and the effect they had on each attribute measure. That null hypothesis was tested, using single-factor *ANOVAs* to evaluate the generational effect of transmission on each trait, in each experimental TC. Working alternative hypotheses for the experimentally produced data were:

i Experiment 2 would produce higher levels of, or more random variation than Experiments 3 and 4, for all attribute measures.

ii Experiment 3 would result in the lowest levels of variation for all attributes, when compared with Experiments 2 and 4, due to the heavily scaffolded nature of one-to-one vertical transmission.

iii The Experiment 4 TCP would result in the emergence of generational norms that would restrict the degree of chosen/target form variation, when compared to Experiments 2 and 3.

Each hypothesis was evaluated using the protocol established for the above individual experiments, as follows:

- Basic dimensional and weight measures
- Roe refinement and shape measures
- The new geometric measures of taper and Euclidean distance
- Area based (cm^2) measures, derived from digital imaging software
- Combinations of each type of measure

By using this approach, the objective was to propose the transmission protocols most likely responsible for the long-term maintenance of a situation that favoured conservative maintenance of a basic tool form, with slow rates of culture evolution, but that was also able to explain differing levels of attribute variation within that form, which could help explain the regional or temporal differences discussed in Chapter 5.

9.2 Basic dimensional measures

As discovered from the individual experimental evaluations covered in Chapters 6, 7 and 8, the basic dimensional measures were unable to provide an effective indication of how overall handaxe form was evolving through multiple generations of copying. The same could be said on a comparative basis. However, the act of contrasting the performance of each dimension provided an initial insight into the respective effect that the differing TCPs or transmission biases were having on the most basic of handaxe attributes. Given the standardised nature of the raw material provided by the moulded porcelain preform cores, the first of those measures, length (Figure 9.1), was shown to demonstrate two quite distinct trajectories that ran counter to the alternative hypotheses; the differing TCPs of Experiment 2 and 4 behaved similarly, both losing length and showing strong downward trends ($R^2 = 0.88$; $p = 0.0002$ and $R^2 = 0.67$; $p = 0.023$ respectively). The initial loss of length experienced in the early generations of Experiment 3 (cultural parenting) was reversed as the knappers in the latter half of the TC produced handaxes longer than the base target form ($R^2 = 0.34$; $p =0.13$). The pattern for Experiment 3 knappers not to consistently lose basic planform size measures continued with increasing handaxe breadth ($R^2 = 0.77$; $p = 0.0043$). The counter-intuitive result here was the rapid decrease in breadth experienced in the many-to-one instructional TCP of Experiment 4 ($R^2 = 0.798$; $p = 0.0068$) which, without more information, appeared to be a worse performance than the unfettered end-state copying TCP of Experiment 2 (Figure 9.2). With regard to thickness, iterational performance in all TCs was erratic, producing no results of statistical significance. The indication from length, breadth and thickness measures was that the differing TCPs were producing distinct results. To effectively evaluate them against the expected outcomes or alternative hypotheses (section 9.1) required a more the integrative approach, which is applied in the following sections of this chapter.

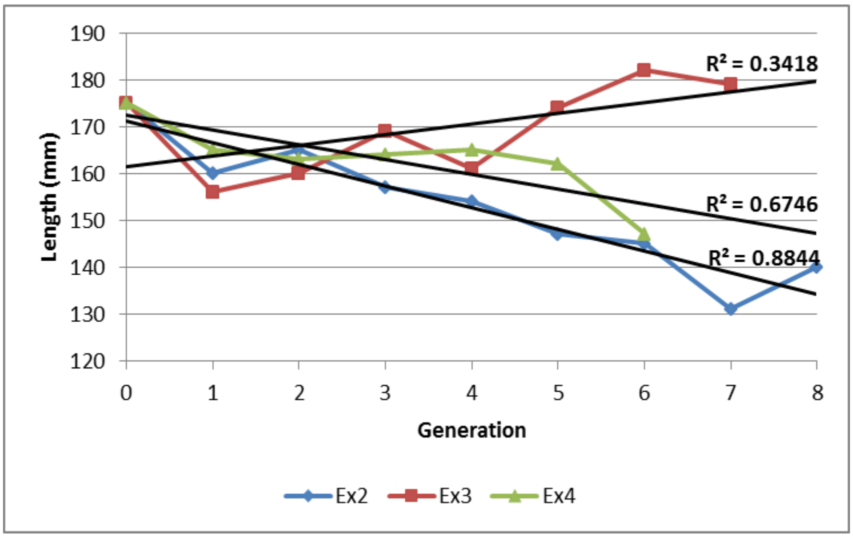


Figure 9.1. Inter-experimental comparison of handaxe length (Ex2, p = 0.0002; Ex3, p = 0.13; Ex4, p = 0.023).

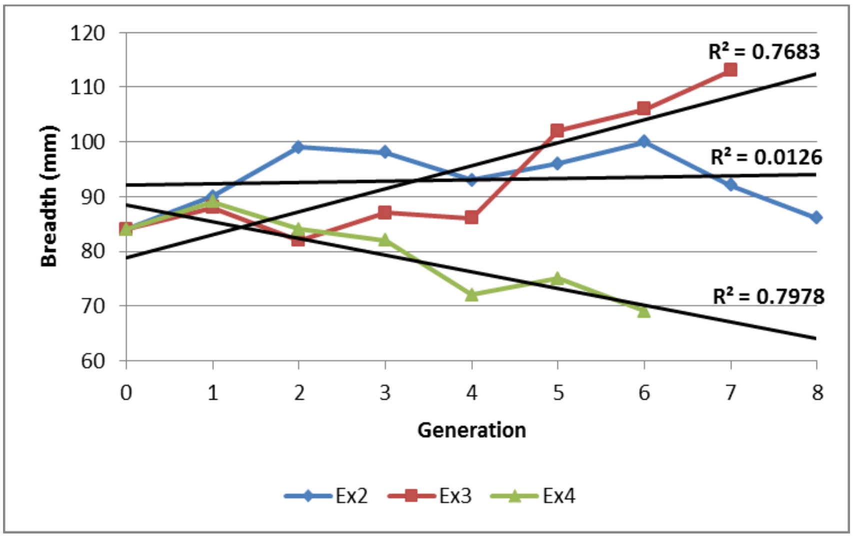


Figure 9.2. Inter-experimental comparison of handaxe breadth (Ex2 was not statistically significant; Ex3, p = 0.0043; Ex4, p = 0.0068).

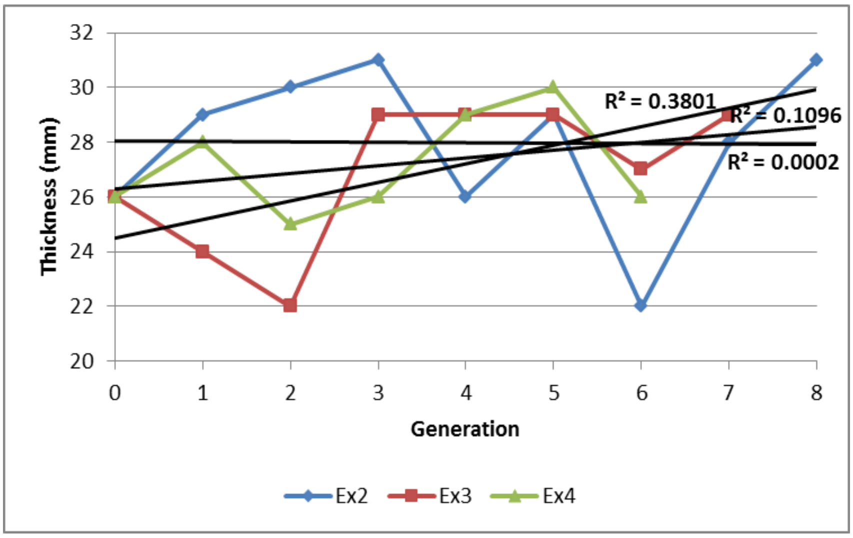


Figure 9.3. Inter-experimental comparison of handaxe thickness (no results were statistically significant).

9.3 Roe refinement ratios

Significant 'between-group' difference was evident in both Roe refinement ratios: $\frac{T1}{L}$ (p = 0.00026) and $\frac{Th}{B}$ (p = 0.029), (Tables 9.1 & 9.2). In terms of fulfilling the alternative hypotheses, especially hypothesis (ii), and as concluded in Chapter 7 and subsequently verified by the cultural parent in Experiment 3 (one-to-one expert instruction), there was a specific instructional focus on handaxe thinning in the TC, for that particular experiment. That emphasis was reflected in the results of $\frac{T1}{L}$ (tip thinning relative to handaxe length), which demonstrated consistently lower ratios (with the exception of Generation 5), when compared to the other TCs (Figure 9.4). Looking more closely at the data, the lower mean ratio and standard deviation achieved by the Experiment 3 intermediate novices demonstrated the effectiveness of the instructional bias at maintaining an efficient thinning process, whilst also maintaining handaxe length. A similar pattern emerged for the $\frac{Th}{B}$ (thickness relative to breadth) ratio of Experiment 3 knappers, where performance was broadly more stable than that achieved by the other TCs (Table 9.2). Of particular note was the relationship between the upward trend and generational performance of the Experiment 4 knappers, who demonstrated a tendency towards the production of thicker, narrower handaxes, not apparent in the other TCs, although largely accounted for by the loss of form between generations 3 and 4 (Figure 9.5). In this context, using Roe ratios, it appeared that cultural parenting was the most effective bias for maintaining and minimising variation in handaxe refinement.

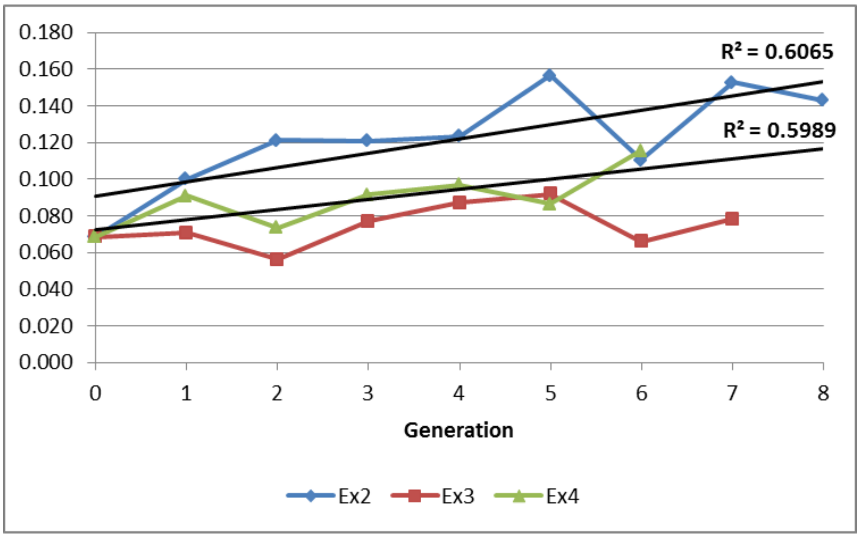


Figure 9.4. Inter-experimental performance of Roe refinement measure $\frac{T1}{L}$.

T1/L Single Factor ANOVA Summary

Groups	*Count*	*Sum*	*Mean*	*Variance*	*Std. Dev.*	*Low*	*High*
Ex2	9	1.096516	0.121835	0.000755	0.02748	0.094355	0.149315
Ex3	8	0.595314	0.074414	0.000134	0.011569	0.062845	0.085983
Ex4	7	0.623599	0.089086	0.000241	0.015512	0.073574	0.104598

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.010064	2	0.005032	12.54727	0.00026	3.4668
Within Groups	0.008422	21	0.000401			
Total	0.018486	23				

Table 9.1. Single-factor *ANOVA* for $\frac{T1}{L}$.

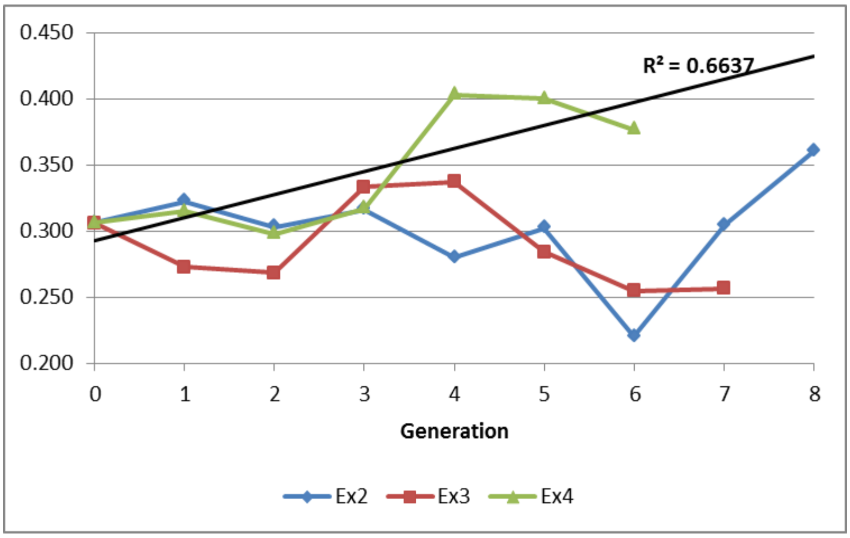


Figure 9.5. Inter-experimental performance of Roe refinement measure $\frac{Th}{B}$.

Th/B Single Factor ANOVA Summary

Groups	*Count*	*Sum*	*Mean*	*Variance*	*Std. Dev.*	*Low*	*High*
Ex2	9	2.713928	0.301548	0.00141	0.037549	0.263999	0.339096
Ex3	8	2.313113	0.289139	0.001073	0.03276	0.256379	0.321899
Ex4	7	2.414771	0.344967	0.002142	0.046285	0.298682	0.391253

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.012683	2	0.006342	4.208241	0.029047	3.4668
Within Groups	0.031646	21	0.001507			
Total	0.044329	23				

Table 9.2. Single-factor *ANOVA* for $\frac{Th}{B}$.

9.4 Roe Shape

Disproving the overarching null hypothesis, the single-factor *ANOVAs* (Tables 9.3 and 9.4) showed there was significant between group difference for two out of three Roe shape attributes: $\frac{B}{L}$ (p = 0.000457) and $\frac{B1}{B2}$ (p = 0.03858). For $\frac{B}{L}$, this was reflected starkly by the differing trajectory of Experiment 4 when compared to Experiments 2 and 3 (Figure 9.6). After an initial rise in $\frac{B}{L}$ in Experiment 4, subsequent generations progressively produced handaxes that became narrower relative to length. Combined with the above analysis of refinement ratios (with an increasing $\frac{Th}{B}$ ratio) this demonstrates that proportionately, length was being preserved at the expense of breadth, but overall, the Ex4 TCP preserved the $\frac{B}{L}$ relationship more effectively than did the TCPs of Experiment 2 and Experiment 3. In line with alternative hypothesis (i), Experiment 2 did produce the highest levels of variation. Running counter to alternative hypotheses (ii) however, Experiment 4 showed that in this context, many-to-one transmission from an accomplished peer group, maintained lower levels of variation ($\boldsymbol{\mu}$ = 0.486 & $\boldsymbol{\sigma}$ = 0.034) than did the TCP of Experiment 3, based on uninstructed end-state copying (*ANOVA* Table 9.3). For $\frac{L1}{L}$ there was no significant between group difference (Figure 9.8 and Table 9.5), reflecting the difficulty experienced by all groups/transmission biases in maintaining the ratio that defined handaxe pointedness, perhaps the attribute most susceptible to non-directional drift.

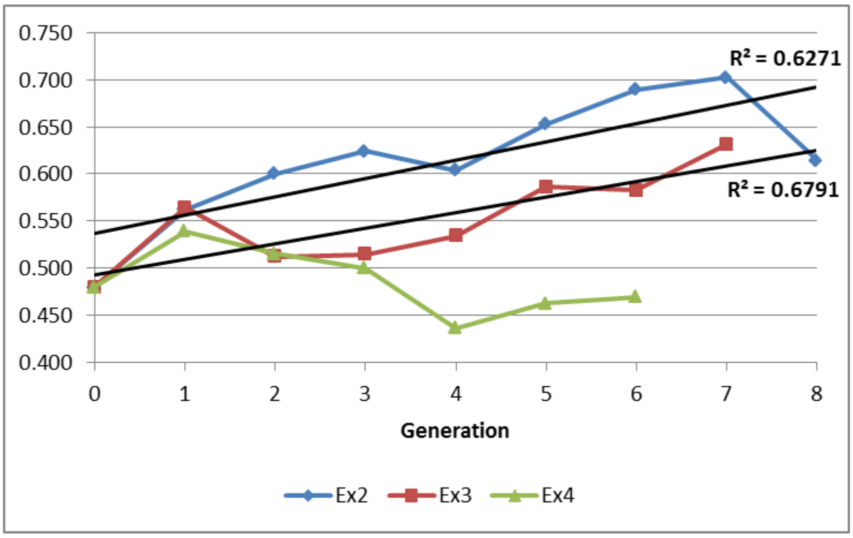


Figure 9.6. Inter-experimental performance of Roe shape measure $\frac{B}{L}$.

B/L Single Factor ANOVA Summary

Groups	*Count*	*Sum*	*Mean*	*Variance*	*Std. Dev.*	*Low*	*High*
Ex2	9	5.529892	0.614432	0.004507	0.067132	0.547301	0.681564
Ex3	8	4.405466	0.550683	0.002423	0.049224	0.50146	0.599907
Ex4	7	3.403446	0.486207	0.001202	0.034674	0.451532	0.520881

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.065052	2	0.032526	11.341	0.000457	3.4668
Within Groups	0.060228	21	0.002868			
Total	0.12528	23				

Table 9.3. Single-factor *ANOVA* for $\frac{B}{L}$.

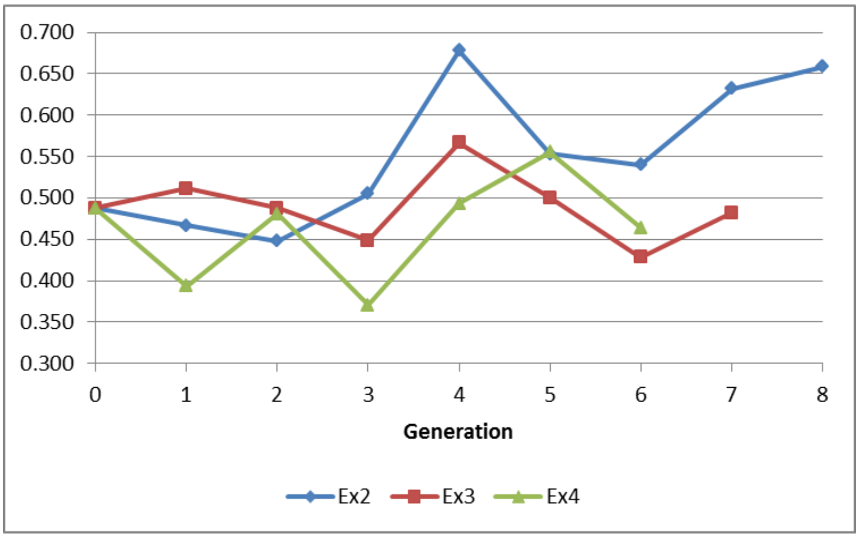


Figure 9.7. Inter-experimental performance of Roe shape measure $\frac{B1}{B2}$.

B1/B2 Single Factor ANOVA Summary

Groups	*Count*	*Sum*	*Mean*	*Variance*	*Std. Dev.*	*Low*	*High*
Ex2	9	4.97032	0.552258	0.007286	0.085357	0.4669	0.637615
Ex3	8	3.912383	0.489048	0.001709	0.04134	0.447707	0.530388
Ex4	7	3.24443	0.46349	0.003973	0.063033	0.400457	0.526523

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.034195	2	0.017097	3.816017	0.038579	3.4668
Within Groups	0.094089	21	0.00448			
Total	0.128284	23				

Table 9.4 Single-factor *ANOVA* for $\frac{B1}{B2}$.

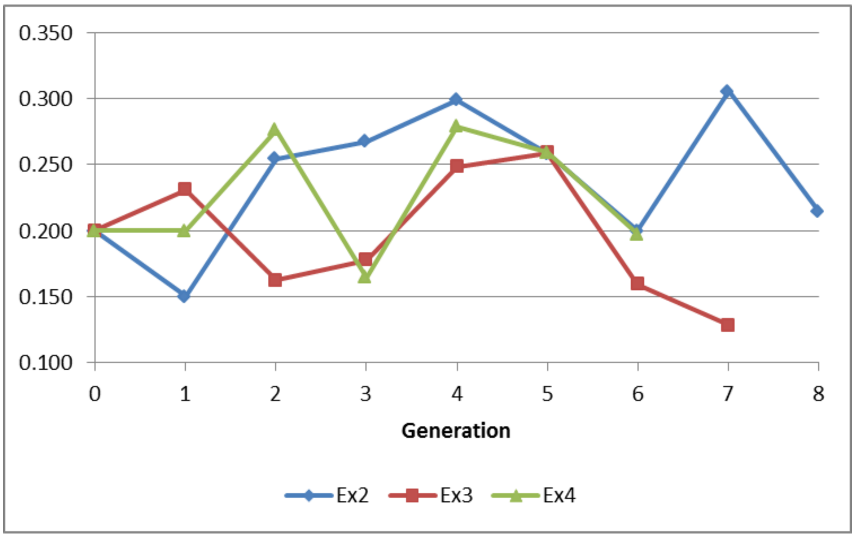


Figure 9.8. Inter-experimental performance of Roe shape measure $\frac{L1}{L}$.

L1/L Single Factor ANOVA Summary

Groups	*Count*	*Sum*	*Mean*	*Variance*	*Std. Dev.*	*Low*	*High*
Ex2	9	2.148895	0.238766	0.002622	0.051203	0.187563	0.289969
Ex3	8	1.565684	0.195711	0.00218	0.046693	0.149018	0.242403
Ex4	7	1.576034	0.225148	0.002056	0.045346	0.179801	0.270494

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.00807	2	0.004035	1.744502	0.199116	3.4668
Within Groups	0.048573	21	0.002313			
Total	0.056644	23				

Table 9.5. Single-factor *ANOVA* for $\frac{L1}{L}$.

9.5 New geometric measures

The purpose of this approach was to take basic handaxe metrics and to increase their diagnostic value, by using combinations of more than two measures (the limiting approach of Roe's ratio system). The aim was to create a more three dimensional handaxe measure, to better gauge the effect that the different TCPs or transmission biases were having on the evolution of form. In the first instance, a measure of taper was used, but instead of the two dimensional use of the two width measures $\frac{B1}{B2}$ as used by Roe, it was also adjusted for handaxe length (Figure 9.6). The second approach was to use the 3D Euclidean distance measure for each iteration (see section 3.5.6 for formulas and full explanation). As shown by the individual experiment chapters, the closest indicator Roe had to a three dimensional measure was mass or handaxe weight. Figure 9.9 shows that there were inter-experimental/TCP differences in mass, the most significant of which was the upward trend shown in the Experiment 3 cultural parenting scenario ($R^2 = 0.67$; $p = 0.013$), running counter to the expectation that one-to-one expert instruction would produce the most stable transmission bias. With chosen form handaxe weight in Experiment 4 ($R^2 = 0.56$, $p = 0.052$) following a similar trajectory to the linear measures of length (Figure 9.1) and breadth (Figure 9.2 and the $\frac{B}{L}$ ratio (Figure 9.6), indications were that transmission in a many-to-one environment was also having a distinct effect on handaxe shape/form, which will be refined by using the new three dimensional measures mentioned above.

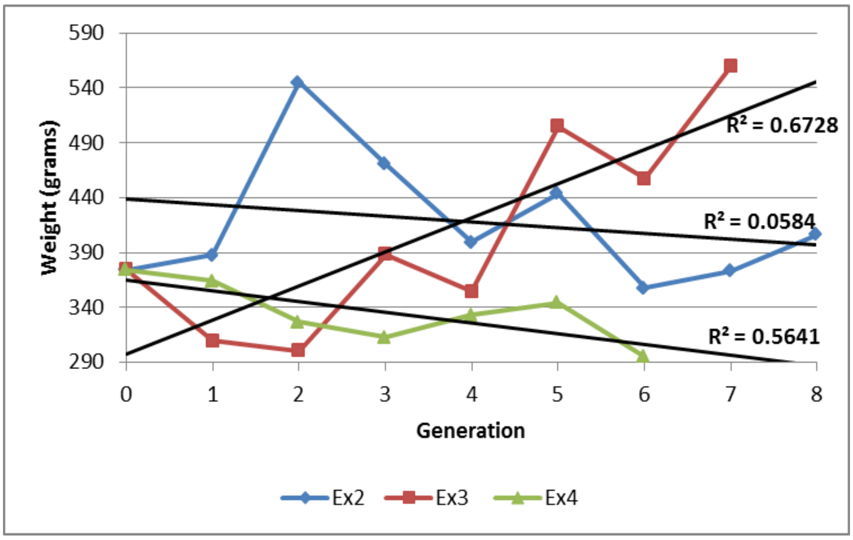


Figure 9.9. Inter-generational performance by chosen form handaxe weight (Ex 3, $p = 0.013$; Ex 4, $p = 0.052$).

Running counter to indicators provided by most other measures, the first real agreement with the null hypothesis that there was no significant variation in the effect that the different TCPs had on handaxe form, came from the new geometric measures. For both measures of taper and 3D Euclidean distance, single-factor *ANOVA* revealed *p*-values of 0.67 and 0.11 respectively, although there were mitigating circumstances. Figure 9.10 illustrates the overlapping nature of length adjusted taper, a result revealing the critical nature of being able to manage multiple attributes simultaneously, illustrated here by comparing the achievement of $\frac{B1}{B2}$ with the achievement of adjusted taper. The variation in degree of taper, recorded by using $\frac{B1}{B2}$ (only two measures), showed it was only marginally significant (*p*-value was close to 0.05 and the *F*-value only just exceeded the *F*-critical). When handaxe length was factored into the equation, significant difference disappeared, likely because differentials in taper were originally accentuated by variation in handaxe length, for example, a handaxe displaying a consistent $\frac{B1}{B2}$ relationship, if it was also shorter than the target form (or vice-versa) would lose its original level of difference (or similarity) when length was factored in. Thus, increased elements of random variation, facilitated by lack of skill in controlling multiple attributes simultaneously, could be seen to erode likely group differentials, created by the varying of transmission biases.

The role played by lack of skill in diminishing the effect of different positive transmission biases was also demonstrated by the 3D Euclidean distance measure. A 'between groups' *p-value* of 0.107 (Table 9.6) was greater than 0.05, but was in the range of demonstrating a moderate level of significance, especially when considering the mean Euclidean distance and standard deviation achieved in Experiment 2 (subject to uninstructed end-state copying) was 25.124mm and 13.05mm respectively. This was far higher than the equivalent figures achieved by Experiments 3 and 4, which were both very close (Table 9.6). For Euclidean distance as an attribute measure, the suggestion is that any positive or direct bias type such as cultural parenting or many-to-one instruction, although not distinctly different in the Euclidean results they produced, will have a more restraining effect on the evolution of form than an unfettered transmission bias, such as uninstructed end-state copying (Figure 9.11). So, in line with alternative hypothesis (i), for Euclidean distance from base target-form, Experiment 2 did produce higher levels of variation than Experiments 3 and 4. This is a factor highlighted further, when changes in Euclidean distance are considered in terms of whether the handaxes became larger or smaller, which is not apparent from looking at Figure 9.11 or Table 9.6 and (as previously discussed), is a weakness of using this measure in isolation.

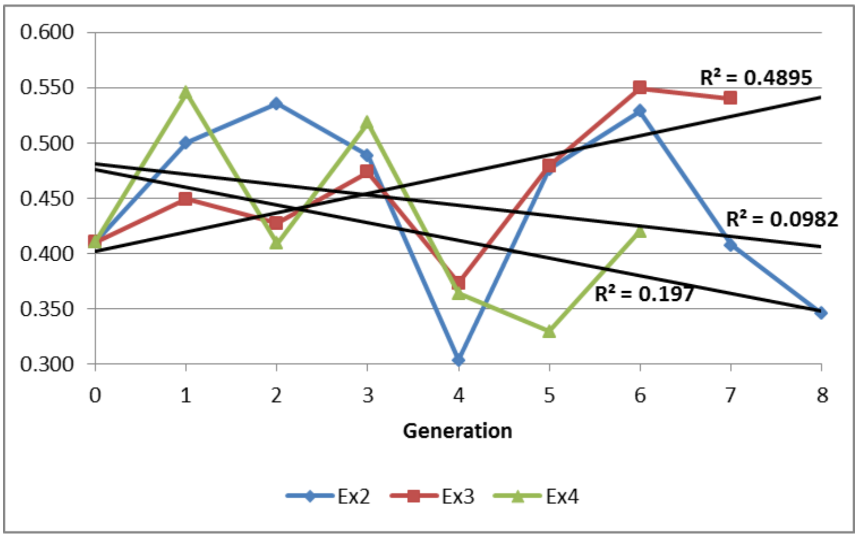


Figure 9.10. Inter-experimental levels of length adjusted taper (Between groups *p* value = 0.67)

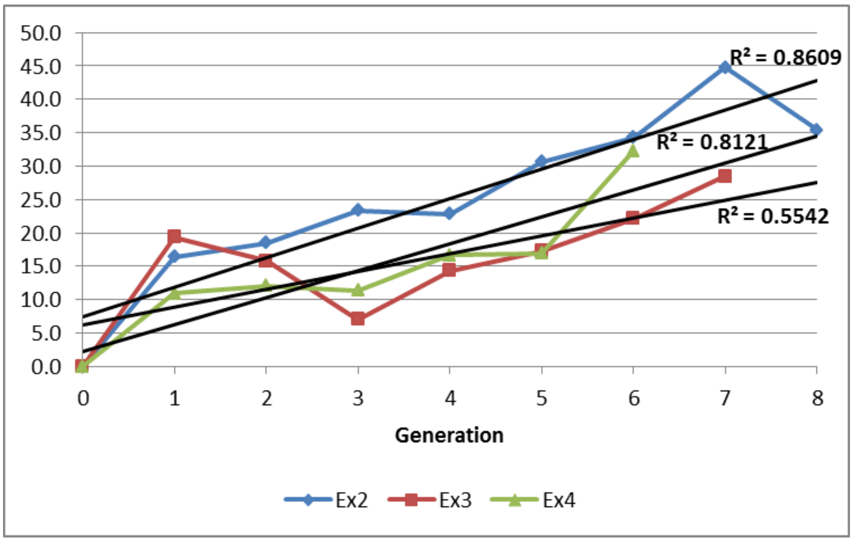


Figure 9.11 Inter-experimental levels of Euclidean distance from base target form. (Between groups *p* value = 0.107)

3D Euclidean distance Anova: Single Factor

SUMMARY

Groups	Count	Sum	Mean	Variance	Std. Dev.	Low	High
Ex2	9	226.112	25.12356	170.523	13.05845	12.06511	38.182
Ex3	8	124.3962	15.54953	77.67104	8.813117	6.736411	24.36265
Ex4	7	100.2436	14.32051	93.91022	9.690729	4.62978	24.01124

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	584.8633	2	292.4316	2.48491	0.107493	3.4668
Within Groups	2471.343	21	117.683			
Total	3056.206	23				

Table 9.6. Single-factor *ANOVA* for 3D Euclidean distance of each chosen form, from the base target form.

9.6 Area based measures and combined ratio analysis

As discussed in Chapters 6 – 8, the shortcoming of the Euclidean distance measure was that despite its attempts to capture 3D form, it was still based on linear measures; a restriction accentuated further, as concluded above, by its inability to reflect the direction in which change was actually occurring. The handaxe area measure, based on an average of the dorsal and ventral area in centimetres square (*ADVA*), provided the solution to both issues. Applying single factor *ANOVA* to the *ADVA* figures overturned the null hypothesis and displayed significant inter-group difference (p = 0.008522) between the three transmission biases on which each of the experimental TCs was based (Table 9.7). The one-to-one expert instruction or cultural parenting of Experiment 3 was the only TCP that managed to arrest the intergenerational loss in size experienced in the other two TCs, with the last three generations producing handaxes with a larger area than the original base target form (Figure 9.12). Despite this trend (R^2 = 6.08, p = 0.02), which also led to the largest mean size and standard deviation, Table 9.7 shows it was Experiment 2 that recorded the highest level of consistency ($\boldsymbol{\mu}$ *ADVA* =100.28cm^2, $\boldsymbol{\sigma}$ = 8.21cm^2). The loss of size or *ADVA* was most predominant in Experiment 4, but was very consistent (R^2 = 0.849 p = 0.003), with little change between generations 2 and 5 (Figure 9.12). When looked at in conjunction with the $\frac{Th}{B}$ and $\frac{B}{L}$ data, there is evidence that in line with alternative hypothesis (iii), the bias generated by the many-to-one instruction was beginning to create a form (smaller and proportionately narrower and thicker) that was distinct from that produced by the other experiments.

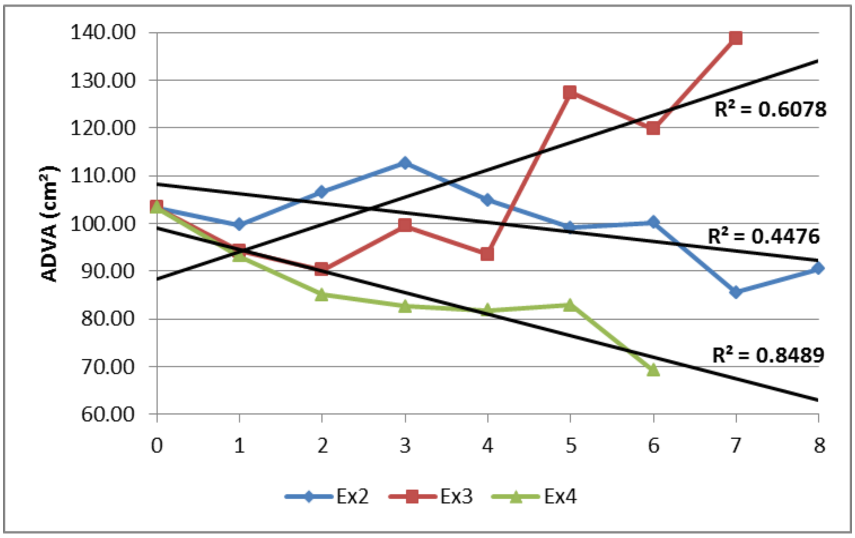


Figure 9.12. Inter-experimental levels of chosen form *ADVA* (cm²).

ADVA Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Mean*	*Variance*	*Std. Dev.*	*Low*	*High*
Ex2	9	902.5	100.2817	67.490	8.2153	92.06641	108.4969
Ex3	8	866.7	108.3431	323.000	17.9722	90.37092	126.3153
Ex4	7	598.3	85.4643	111.449	10.5569	74.90735	96.0212

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1992.7	2	996.3278	6.030314	0.008522	3.4668
Within Groups	3469.6	21	165.2199			
Total	5462.3	23				

Table 9.7. Single-factor *ANOVA* for *ADVA* (cm²).

To verify the patterns indicated by $\frac{Th}{B}$ (above), the $\frac{Th}{\sqrt{ADVA}}$ ratio was used, containing its area based (cm²) component. Figure 9.13 produced results showing a strongly significant refinement/size relationship for the many-to-one instructional TCP of Experiment 4 ($R^2 = 0.727$, $p = 0.015$), as handaxes were again demonstrated to become thicker and smaller through the generations of the TC. With regard to inter-experiment performance, despite the distinct pattern of the Experiment 4 knappers, one-way *ANOVA* only confirmed moderate between-group variation (p = 0.065); perhaps a result of the erratic and overlapping performance of the uninstructed Experiment 2 knappers. The relatively stable ratio experienced in Experiment 3, viewed in combination with the significant increases in size (Figure 9.12) are testament to the effect of one-to-one transmission from an expert knapper. In this scenario, the impact of direct instruction from the cultural parent was the creation of handaxes that were proportionately thinner than those from the other groups, as a function of their increasing size. This result again reflected the emphasis placed on handaxe thinning by the cultural parent; one of the more difficult aspects of knapping and a direct consequence of strike-by-strike guidance covering platform preparation, angle, direction and velocity of strike. These were the key components of the bio-mechanic process identified by Bril *et al* (2010) and discussed in section 2.1.2, as requiring repeated practise of the relevant bodily actions necessary to complete the transition in skill level from intermediate novice to expert knapper; a process that Experiment 3 has shown, also requires direct instruction.

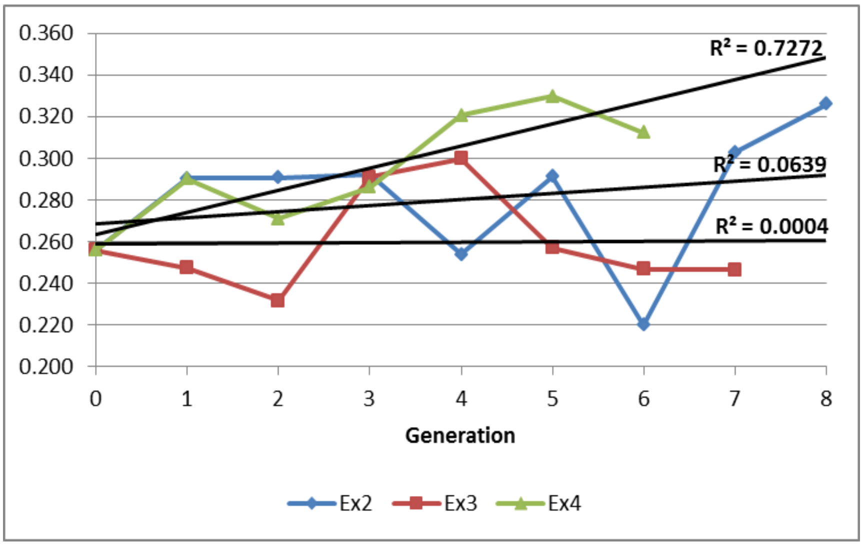


Figure 9.13. . Inter-experimental levels of chosen form $\frac{Th}{\sqrt{ADVA}}$.

Th/√ADVA Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Mean*	*Variance*	*Std. Dev*	*Low*	*High*
Ex2	9	2.52241	0.280268	0.001002	0.031658	0.24861	0.311925
Ex3	8	2.075015	0.259377	0.000557	0.023607	0.23577	0.282984
Ex4	7	2.065329	0.295047	0.000729	0.026996	0.26805	0.322043

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.004851	2	0.002426	3.126853	0.064764	3.4668
Within Groups	0.016291	21	0.000776			
Total	0.021143	23				

Table 9.8. Single-factor *ANOVA* for $\frac{Th}{\sqrt{ADVA}}$

9.7 Handaxe symmetry

As shown in Figure 9.14 and concluded in each of the individual experiment chapters, *VAI* or handaxe symmetry was consistently achieved at ‘very high’ levels (with *VAI* scores between 1.5 and 3.0). Analysis of inter-group difference showed no statistically significant between group variation (p = 0.17, Table 9.9), a fact that suggests that transmission bias makes little difference to the achievement of symmetry. This was true even in Experiment 2, where subject to uninstructed end-state copying the effect on other attributes generally displayed more variation and less consistency. The underlying conclusion here is that handaxe symmetry, once understood as a concept and mastered as a knapping outcome, was relatively easy to achieve and was dominant to other attributes (both shape and refinement) in the transmission process

The exception to this ‘very high’ achievement of symmetry (although not statistically significant) was Experiment 3, where levels although still ‘high’, fell below what was achieved in the TCs of Experiments 2 and 4. This difference was reflected in the descriptive statistics where standard deviation for Experiment 3 was 1.07 and the high range of that standard deviation, at a *VAI* of 4.06 was greater than the 3.06 and 2.78 of Experiments 2 and 4 respectively. This result runs counter to those of other attributes such as maintenance of handaxe size or refinement measure $\frac{Th}{\sqrt{ADVA}}$, where Experiment 3 maintained more positive or consistent results than those achieved in the other experiments. This suggests that, when subject to the heavily scaffolded bias of cultural parenting, although positive results were achieved in the attribute of focus (size and handaxe thinning technique in this case), it detracted from the achievement of attributes normally achieved and passed on with ease, when subject to other transmission biases.

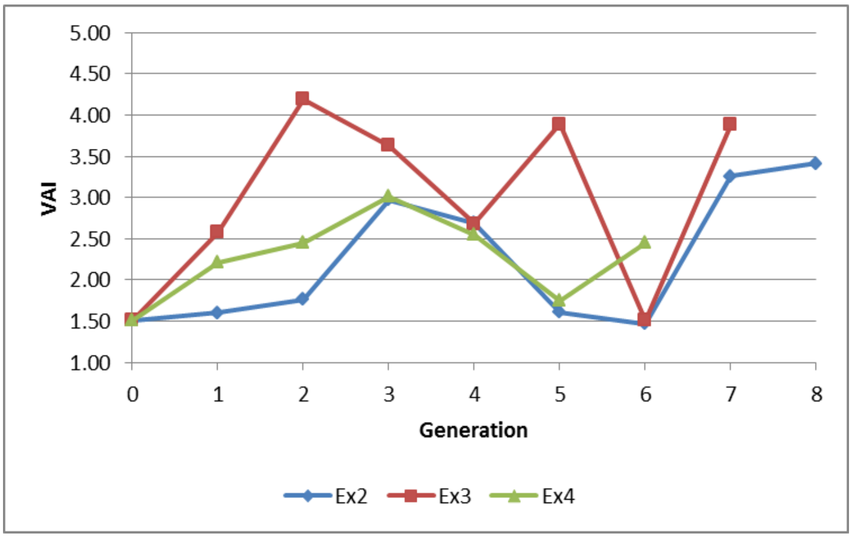


Figure 9.14. Inter-experimental levels of chosen form *VAI*.

VAI Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Mean*	*Variance*	*Std. Dev.*	*Low*	*High*
Ex2	9	20.28	2.2533	0.6632	0.8144	1.4389	3.0677
Ex3	8	23.87	2.9838	1.1566	1.0755	1.9083	4.0592
Ex4	7	15.93	2.2757	0.2570	0.5070	1.7687	2.7827

ANOVA

ce of Varic	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between (	2.771574	2	1.3858	1.9473	0.1676	3.4668
Within Gr(	14.94436	21	0.7116			
Total	17.71593	23				

Table 9.9. Single-factor *ANOVA* for *VAI*.

With regard to alternative hypothesis (iii), the achievement of *VAI* provides further support for the idea that the many-to-one transmission of Experiment 4 would restrict variation more than the other biases of Experiments 2 and 3. Although levels were not as low as those achieved in Experiment 2, there was less variation, with a standard deviation of 0.5 *VAI* and the most compressed distribution range of between 1.76 *VAI* (low) and 2.78 *VAI* (high), (Table 9.9). On an inter-generational level, Figure 8.21 illustrated the tightness of clusters for VAI achievement of all handaxes knapped in each generation. However, there was no significant difference between the overall *VAI* achievement of any single specific generation, compared to all other generations (a result derived from Tukey's post hoc testing, run on a single-factor *ANOVA*). On this basis, although Experiment 4 regulated variation efficiently compared to the other TCPs, it did not do so distinctly enough to create any norms that were different on an inter-generational basis and that would consequently act to restrict the attempted achievement of the *VAI* of the original target form, as it passed through the transmission chain.

9.8. Discussion

The undoubted overall trend, demonstrated by all TCs and all transmission biases, was one of progressive movement away from the form of the base or original target form handaxe, illustrated here by the Euclidean distance measure (Figure 9.11). Although there was no significant difference between the performance of each of the different transmission biases (for Euclidean distance, see section 9.5 for discussion), in all TCs the high R^2 values signified there was a positive and direct relationship between the knapping performance of each generation of the TC and the resultant cumulative variation in overall form; a trend that looked most pronounced in the TC of Experiment 2 (R^2 = 0.86) where knapping was subject to uninstructed end-state copying, the most unfettered form of cultural transmission experimented with in the TCPs of this project.

Within the overall trend of increasing variation, changes in transmission bias did effect the relative achievement and evolution of different attribute combinations. This was effectively illustrated first in Experiment 2, where, due to relatively low levels of skill and a lack of selective pressure because of the uninstructed end-state copying TCP, the result was a thickening in terms of refinement and a convergence of planform shape, between what began as two distinct handaxe forms: ovate and point. Convergence stemmed from the inability to manage multiple shape defining attributes, on a simultaneous basis, particularly $\frac{B}{L}$ and $\frac{B1}{B2}$ (Figure 6.10). This led to knapping over successive generations of transmission that eroded the defining extremities of each handaxe type, resulting in the appearance of a more homogenous, cordiform handaxe shape. Loss of refinement in Experiment 2 was apparent from both Roe measures, significantly so for $\frac{T1}{L}$ for pointed handaxes (Figure 6.7) and the area based measure $\frac{Th}{\sqrt{ADVA}}$. Much of that variation was again due to skill related issues, rather than perceptual limitation or non-directional drift. Inability to maintain length was more pronounced than in any other experiment (Figure 9.1), and loss of planform area showed a moderate downward trend (Figure 9.12). These factors, in combination with poor thinning skills, which are interlinked aspects of knapping, meant that the emerging cordiform also evolved into a smaller, thicker handaxe, that despite change in shape and size experienced no significant loss in weight (Figure 9.9); all factors further supporting the idea that lack of knapping skill was accentuating the effect of uninstructed end-state copying.

The TCP of Experiment 4 created a distinct effect on the transmission of handaxe form and did perform in agreement with alternative hypothesis (*iii*.) by creating a form that was different and specific to the groups knapping in each generation. The first indication of this was provided by the basic dimensional measures, where after the initial loss of length between the base target form and Generation 1, the attribute remained stable for Generations 2 – 5, in contrast to the TCs of Experiments 2 and 3, where there were respective decreases and increases on a generational basis (Figure 9.1). This relatively stable maintenance of a shorter handaxe length was accompanied by a loss of handaxe breadth (Figure 9.2). Both these measures were verified by the Roe refinement ratios, suggesting that the norm being created in Experiment 4 was the production of shorter, thicker, narrower handaxes (Figures 9.5 and 9.6). Once form was established, the constancy of size maintenance was supported by the *ADVA* measure in Generations 2 - 5 (Figure 9.12).

Whilst handaxe refinement deteriorated in Experiment 2 (cumulatively) and Experiment 4 (held on a consistent basis), all measures of refinement ($\frac{T1}{L}$, $\frac{Th}{B}$, $\frac{Th}{\sqrt{ADVA}}$) were transmitted most effectively by the one-to-one, expert instruction TCP of Experiment 3. This refinement was achieved without the loss of length, breadth and *ADVA* experienced in the other TCPs (Figures 9.1, 9.2 & 9.12), vindicating the deliberate focus on handaxe thinning techniques, provided by the teaching of the cultural parent. Despite inter-experimental attribute differences, the constant trait throughout Experiments 2 and 4 was handaxe symmetry. This was especially notable in the case of Experiment 2, where the copying and subsequent transmission of other attributes deteriorated quickly. As discussed, the loss of 'very high' levels of symmetry in Experiment 3 was attributed to the instructional emphasis placed on handaxe thinning, a difficult skill to master, in contrast to symmetry which, even with the concession created by the TCP of Experiment 3, was still managed and transmitted to a relatively high level.

The level of skill, related to the complexity of the knapping task and reproduction of specific attributes or attribute combinations, has become a recognised factor accounting for variation in all four transmission chain experiments covered in this thesis. As the participants in each experiment were drawn from the same pool of knappers, the structure of the TCP also has to be regarded as a primary factor in accounting for the variation identified between each of the experiments discussed above. In this context, it is possible to identify the characteristics of the TCPs used in these experiments, and map them on to some of the formally defined transmission biases discussed in Chapter 2 and schematically illustrated in Figure 2.9. On this basis, Table 9.10

shows how each experimental TCP could align with a specific type of transmission bias.

Experiment	TCP	Transmission Bias
2	Uninstructed end-state copying in TCs with a single member per generation	Horizontal transmission and guided variation
3	One-to-one expert instruction from a cultural parent	Vertical transmission
4	Many-to-one instruction from an accomplished peer group	Oblique transmission and conformist bias

Table 9.10. Identifying each experimental TCP with a formal type of transmission bias.

As discussed in Chapter 5, it was likely that population density and hominin group size in the Middle and Lower Pleistocene were both low, and therefore subject to instability that would likely be reflected in the types of cultural transmission able to operate. Those types of transmission would have to account for limited variation over long time periods and seeming loss of cultural development but also allow for the existence of different traditions on a temporal and macro-regional basis. The uninstructed end-state copying of Experiment 2 demonstrated how, with relatively low levels of knapping skill, form, via attribute variation, was subject to extensive change. This TCP could be analogous to a situation where a skilled hominin knapper died or was somehow removed or separated from the group. In this instance, if transmission occurred on a purely horizontal basis, low levels of skill could result in the types of variation displayed by the ovate and pointed chains of TC1 and TC2. Here, the increasing $\frac{B}{L}$ ratio of TC1 showed a loss of ovate form and the accompanying growth of $\frac{B1}{B2}$ in TC2 provided evidence of pointedness being lost and convergence with the taper profile of a more ovate or cordiform handaxe. Euclidean distance from base target form was strongest for the pointed TC2 handaxes of Experiment 2 (R^2 = 0.86, p = 0.0002), again reflecting how easy loss of form was when transmission was unregulated in manner akin to guided variation. In both TCs, despite variation, basic handaxe from was maintained and anchored around the effective maintenance of symmetry. Following the demographic models of Lycett & von Cramon-Taubadel (2008) and Lycett & Norton (2010), a highly dispersed population with low levels of social interconnectedness are key factors in preventing the effective transfer and maintenance of skill levels on an inter-generational basis. With loss of key skilled personnel, a system of horizontal transmission in depleted populations could, as demonstrated by Experiment 2, lead to a breakdown in effective cultural transmission. Taken to its extreme, this scenario could ultimately result in a total loss of skill, resulting in the failure to transmit the strongest traits of symmetry and bifacial working. This could, as proposed by Lycett & von Cramon-Taubadel (2008) and Lycett & Norton (2010), explain Acheulean phenomena such as the Clactonian or East Asian assemblages, where handaxes are absent and there was a possible reversal to solely Mode 1 (Clark, 1968) or core and flake based technology.

Despite the seeming efficacy of linking low population density with diminishing skill levels and horizontal transmission, it does not preclude the concept of cultural parenting or vertical transmission from an expert knapper within a small population, resulting in faithful transmission of artefact attributes. Experiment 3, where again, the knappers were drawn from the same pool as for Experiment 2, demonstrated the effectiveness of direct instruction and offered explanation for the maintenance of and limited nature of variation within the archaeological record of the Acheulean. It is exactly this type of vertical transmission which could account for the presence of two different handaxe groups as at Kilombe (Gowlett, 2005) where, as discussed in Chapter 5, one set was large and refined and attributed to an expert knapper and one set less refined and therefore attributed to a less skilled agent. This is a possible explanation but the differences could also represent the result of cultural parenting where, as in Experiment 3, novices who produced large refined handaxes under conditions of cultural parenting, when on their own, found it difficult to reproduce the techniques they had previously been taught. This is a situation aptly illustrated by the differences between the handaxes in Experiment 3 and Experiment 4, when all knappers had experienced direct cultural parenting, but when subject to the differing bias of Experiment 4, produced a different, smaller and less refined type of handaxe compared to what was produced previously in

Experiment 3 because they lacked the skill, gained from repeated and extensive practise, to achieve the target form when knapping independently of the cultural parent (see Figures 9.1, 9.4, 9.5, 9.6, 9.12 & 9.13 for contrast).

With the differences between Experiment 3 and 4 (and 2) in mind, the creation of shorter, thicker handaxes produced by the intermediate or skilled novice knappers of Experiment 4 was not just the product of the chosen form as it passed through the TC. There was some evidence that the many-to-one instructional regime was producing a degree of conformist bias, and in one instance, in Generation 2, away from the attribute patterns of the target group (*ANOVA* revealed a significant difference between Generation 2 and Generation 6). The formation of this kind of group norm (i.e. the regular production of smaller, less refined handaxes) is the type of dynamic likely enforced by the conservative handaxe rule-sets of the group, as discussed in Chapter 5 (with reference to Gowlett, 2005), where deviation from the established template was acceptable for only one or two attributes, for example $\frac{L1}{L}$. This type of group norm may not require conscious enforcing and, as recognised by McNabb *et al* (2004), could simply become habituated within the techno-cultural framework of the hominin group. Differing occurrences of this type of bias, if perpetuated on a large enough spatial (and temporal) scale, could also be regarded as a likely cause of the macro-regional variation reported by Lycett & Gowlett (2008) and Wynn & Tierson (1990), as discussed in Chapter 5. In this situation, conformism perpetuated by many-to-one instruction, in conjunction with isolated populations, could have created the patterns of handaxe conformity seen in the archaeological record of the Acheulean.

Within the broad framework of sparse and fragile population levels and their subsequent effect on differing types of transmission bias, the presence of variation in levels of knapping skill is an underrated factor in accounting for the creation of variation, or maintenance of stasis within the Acheulean. The issue of learning strategy explored by Laland (2004) focused on who individuals choose to copy from in social learning situations. In small group sizes, where knapping expertise has been lost, the concept of choice in deciding who to copy from may have been reduced to ‘copy what’s available’, even if it is technically inferior to what may have (unknowingly) come before. Experiment 4 showed that once the ideal or base target form had been lost due to lack of skill, a group norm may have emerged and survived, even though it was technically inferior to what went before. This situation effectively becomes one of maladaptive learning where, in examples drawn from animal behaviour (Giraldeau *et al,* 2002; Laland, 2004; Laland & Williams, 1998), learning from socially generated queues overrides and can limit potentially profitable individual learning. In these situations, it can take extended periods of time for individuals to break the socially acquired information or bias, and establish new methodologies or attribute patterns. This is evidenced by the easy loss of refinement attributes by the groups in Experiment 4 (and individuals in Experiment 2), and the fact that subject to TCs of limited duration, they were never actually re-established.

The trait that survived most consistently across all the Acheulean experiments in this thesis was symmetry. Within the conservative group handaxe template idea established by Gowlett (2005) and discussed above, symmetry could be positioned as a sacrosanct trait that the norm established by hominin groups would not permit deviation from. But that would not explain why it persisted in three different TCPs when no instruction on the specific preservation of symmetry, over and above any other attributes, was given by the project organiser (in a similar vein to the findings of Ward (1949), discussed in section 2.2.2). In a knapping context, it would appear that the imposition of planform symmetry required less skill than the maintenance of refinement attributes or handaxe length. In a neurological context, there is the possibility that the importance and recognition of symmetry became behaviourally hardwired. This was due to an expansion of the hominin brain, specifically the superior parietal lobe, which occurred throughout the Lower and Middle Pleistocene; a period coinciding with the increased emphasis placed on symmetry in the Acheulean, as an evolutionary adaptive change was exapted for the production of stone tools, specifically the bifacial and symmetrically worked handaxe (Hodgson, 2005; Hodgson, 2009a; Hodgson, 2009b). This would lend weight to explaining the seemingly automatic prevalence of symmetry within Experiments 2, 3 and 4 and the accuracy with which the trait was transmitted throughout each of the respective TCs. However, it does not consider the relative ease with which stone can be chipped away to maintain planform symmetry, when compared with the levels of honed skill and practiced technique required to prepare and isolate effective striking platforms. Nor does it consider the *connaissance and savoir-faire* required to master the biomechanics of strike action (Chapter 2) required to remove the invasive biface thinning flakes needed to produce refined handaxes, without losing size (*ADVA*). This was something only achieved in Experiment 3, when the knappers were heavily scaffolded by the one-to-one expert instruction provided by their cultural parent. The difficulty of this process was also noted by Stout *et al* (2014) who, over the course of 17 experiments, stated that the process required in faceting or steepening the platform before it was struck, even as a concept seemed counter-intuitive, and required that the knappers had reached expert levels of skill before it could be performed effectively. On this basis, they concluded it would be more likely to be lost as a trait, when subject to drift in the culture evolutionary process that small hominin populations would have often been subject to. The traits more likely survive, or crucially be more easily reinvented if lost, would be the more basic or less skilled processes of bifacial shaping, and as noted by the longevity of survival in the archaeological record, and during the experiments in this thesis, planform symmetry.

The main purpose of the Stout *et al* (2014) study was to compare the complexity of platform preparation of the Acheulean artefacts from Boxgrove, an Early Middle Pleistocene site on the south coast of England, with levels of platform preparation achieved by a range of contemporary knappers of three different ability levels: inexperienced, novice and expert. As alluded to above, the analysis of flake removals, both prepared and unprepared, from all debitage scatters, revealed that the level of skill and preparation involved in the Boxgrove flakes most closely matched those of the expert group of knappers from the contemporary samples. They went on to suggest that level of skill was also likely to have accounted for the similarities in size and $\frac{B}{Th}$ ratio between the intermediate and expert contemporaries and Boxgrove knappers. From these results, Stout *et al's* (2014) conclusion speculated that to achieve this level of skill would have necessitated regular and deliberate practice, in a social context.

9.8.1 Comparing experimental results with the archaeological record

To test the idea of skill maintained and progressed (from intermediate to expert) through practice, and to generate hypotheses as to the type of transmission techniques likely used in the Middle Pleistocene, would involve testing the knapped output of Experiments 2, 3 and 4 against archaeological handaxe data. To gain access to such metric data, the Archaeological Data Services (ADS) Acheulean biface database (Marshall *et al,* 2002) was utilised. As not all measures taken were the same across both datasets (a common problem in Palaeolithic research), it meant utilising one of the strengths of the Roe (1968) measures, that is, their broad and long lasting acceptance throughout the discipline as standardised measures, by using weight, length, breadth, thickness, and breadth at L1. On this basis, $\frac{B}{L}$ and $\frac{L1}{L}$ were used as the common measures of shape, and $\frac{Th}{B}$ the common measure of refinement. Marshall *et al* (2002) had also included an area based measure, used here to produce a further measure of refinement (as in Experiment 2, 3 & 4), as a component of the $\frac{Th}{\sqrt{Area}}$ formula. In common with methodology used in Experiment 1, to provide valid inter-assemblage comparisons between experimental and archaeological data, the coefficient of variation (CV) was calculated for each of the above attributes (see section 3.5.2 for formula and details).

As a caveat to the comparison of handaxes produced by contemporary knappers (*Homo sapiens*) with those produced by a Middle Pleistocene hominin, most likely *Homo heidelbergensis*, there are obvious cognitive differences not only in brain size but also neural organisation (Wynn, 2002; Stout *et al,* 2008). This should also be viewed in conjunction with the differences in environment between handaxes produced in confined and specific laboratory conditions and those produced in situations that likely carried fluid and changing transmission biases and the implication of selective pressure. In an experimental context, especially with a skill dependent craft like stone knapping, there is little that can be done about this except to recognise such differences when drawing conclusions. However, what this approach does offer is the addition of experimentally produced data to be used in conjunction with archaeological data, in an attempt to translate culturally produced phenomenon, such as differing levels of handaxe variation within a confined or conservative tool form, more effectively.

To ensure the archaeological data was as comparable as possible, the ADS data base was filtered using three criteria. Firstly, it sorted all handaxes with a $\frac{L1}{L}$ ratio of less than 0.35 to ensure only pointed handaxes were selected. Secondly, it was asked to include only handaxes knapped on flint/chert, so from a raw material perspective, the pieces selected would be closest to the porcelain cores used in the experimental TCPs. And thirdly, in terms of condition, they had to be fresh to ensure the planform profile had not been changed from that intended by the knapper, as a result of post depositional factors (Grosman *et al,* 2011). The results produced output from 3 of the 21 sites recorded on the database: Boxgrove, Cuxton and Tabun.

9.8.1.2 The sites

Boxgrove

Dating to around 480kya, the Acheulean artefacts excavated at Boxgrove, from *in situ* contexts, are renowned for their fresh and highly preserved nature (Roberts & Parfitt, 1999). Amongst the assemblages were examples of what are recognised as finely knapped Early Middle Pleistocene handaxes (Iovita & McPherron, 2011; Roberts & Parfitt, 1999). Good quality flint was readily available from the slopes of chalk cliffs that bounded the site location, with evidence for testing and abandoning nodules that were not considered of high enough quality to knap (Pope & Roberts, 2005). From this behaviour it is reasonable to assume that restrictions placed on knapping, due to raw material, were not an issue for the hominins of Boxgrove. A human tibia excavated in association with stone tools in the silts of Boxgrove was assigned to *Homo heidelbergensis* (Roberts, Stringer & Parfitt, 1994), attributing authorship of the tool assemblages to what Stringer *et al* (1998) more tentatively called a non-modern hominin.

Cuxton

This site is situated on a palaeo-gravel terrace of the River Medway, Kent, in the south-east of England (Tester, 1965). Its location in the chalk of the North Downs provided the occupying hominins with access to flint from varying sources, notably the flint rich outcrops less than two kilometres from the site, which can be dated to between OIS 10 and OIS 8 or 374-300kya (Shaw & White, 2003). The Cuxton handaxe assemblage was reported by Tester (1965) as being predominantly roughly made and pointed in shape, with cortical butts. However, in their discussion of the assemblage composition, Shaw & White (2003) mentioned signs of finer knapping displayed on some of the Cuxton handaxes (compared to Fordwich, another Middle Acheulean site in Kent), which they attributed to soft hammer work. They went on to attribute this to a culturally produced phenomenon that was likely demonstrating micro-regional/inter-group variation manifesting itself in the technical approach, as opposed to handaxe shape. In terms of cultural transmission, especially in the Acheulean of the Middle Pleistocene, this is an important distinction to make and one that is often hidden by looking at final artefact form in isolation. The combination of techno-stylistic variation can only strengthen the case for culturally produced variation, within a broad artefactual form, enforced to differing degrees by transmission bias.

Tabun

Originally excavated by Dorothy Garrod between 1929 and 1934, Tabun Cave is situated in the Wadi Mughara, in the low rolling limestone hills, on the western edge of Mt. Carmel, overlooking the three kilometre coastal plain, 20 kilometres south of Haifa, Israel (Jelenik *et al,* 1973). The 25 meter sequence was originally divided into seven main layers (A-G) by Garrod (Garrod & Bate, 1937) which were refined by the subsequent Jelenik excavations into 14 stratigraphic units subdivided into 90 separate beds. Between 1975 and 2003, A. Ronen conducted the third excavation, assigning the entire sequence to its respective Mousterian, Yarbrudian, Acheulean and Tayacian cultural entities (Ronen *et al*, 2000; Gisis & Ronen, 2006). Jelenik's Beds 73 - 90 (Garrod's original layers E – G) associated with the later Acheulean were subsequently dated by thermoluminescence to 306kya-360kya (Mercier *et al,* 1995). Human remains were restricted to an almost complete skeleton (Tabun I) and an isolated mandible (Tabun II), both excavated from Garrod's Level C and attributed to *Homo neanderthalensis* (McCown & Keith, 1939); Tabun II was subsequently attributed as a late archaic hominin (Stefan & Trinkaus, 1998). The Mercier *el al* (1995) dating places them at between 171(+/-17) kya which, given the stratigraphic relationship between Level C or Jelinek beds 17 - 26 and the underlying Jelinek beds 73 - 90 would likely position the authors of the Acheulean handaxes as *Homo heidelbergensis* (in common with Cuxton and Boxgrove). In terms of raw material, McPherron (2003: 61) stated that most of it was locally available and that quality was very good with little variation. Within this observation, account has to be made for the fact that he was primarily trying to support/test his own theory that handaxe variability was largely the product of reduction strategy (as discussed in Chapter 5). That said, evidence of a consistent and high quality raw material also helps to minimise that factor when accounting for variation as a product of cultural transmission. McPherron (2003) went on to observe that the majority of assemblages were indeterminate, meaning there was a continuum of variation that prevented them from fitting into the point/ovate dichotomy created by the Roe (1968) system. Further to that, he stated that refinement (defined as $\frac{Th}{B}$) was fairly constant at Tabun, regardless of changes in raw material/blank type and changes in size (McPherron, 2003: 62), which could point towards a handaxe form that was, skill levels aside, maintained and transmitted by a specific type of transmission bias.

9.8.1.3 The comparative data

Based on the filters discussed in 9.8.1 above, to gain an initial view of variation based purely on mass (as a non-dimensional attribute), single-factor *ANOVA* was run on the weight data and as expected from an analysis covering six different assemblages, there was a significant between groups variation ($p = < 0.000$). Looking at specific relationships, the mean based data (Table 9.11a) shows the relative closeness of the CVs for the three sets of experimental data which, given the standardised shape and weight of the porcelain preform cores, was also to be expected. The point of note in this respect was that the lowest standard deviation of 56.94 grams was produced by the handaxes of Experiment 4, a fact indicative of the tight knapping performance produced by the many-to-one TCP on which this transmission chain was based. When Levene's equality of variance was run on the weight data, the distinct performance of the Experiment 4 groups was verified as the variance was shown to be significantly different when compared with assemblages (on a pair-wise basis) from all other experiments (Table 9.11b). For the archaeological data, the surprising figure was the relatively low CV of 0.34 produced by the Boxgrove handaxes which, although not offering levels of variation as low as those of the regulated cores from the experimental assemblages, did demonstrate a more consistent knapping performance when compared with Cuxton and Tabun. The equality of variation between Boxgrove and Cuxton was also shown to have moderate statistical significance ($p = 0.06$, Table 9.11b).

Assemblage	*Count*	*Sum*	*Mean*	*Variance*	*Std. Dev.*	*Low*	*High*	*CV*
Boxgrove	24	6052.00	252.17	7147.10	84.54	167.63	336.71	0.34
Cuxton	19	4669.00	245.74	31312.98	176.95	68.78	422.69	0.72
Tabun	85	10987.00	129.26	8401.05	91.66	37.60	220.92	0.71
Ex2	14	5449.20	389.23	8817.99	93.90	295.32	483.13	0.24
Ex3	12	4824.80	402.07	8150.52	90.28	311.79	492.35	0.22
Ex4	48	15239.30	317.49	3241.72	56.94	260.55	374.42	0.18

Table 9.11a. CV and mean based data for weight measures of experimental and archaeological handaxes from ADS database.

	Boxgrove	Cuxton	Tabun	Ex2	Ex3	Ex4
Boxgrove	-	0.060	0.563	0.926	0.762	0.004
Cuxton	0.060	-	0.000	0.034	0.580	0.000
Tabun	0.563	0.000	-	0.721	0.513	0.042
Ex2	0.926	0.034	0.721	-	0.768	0.039
Ex3	0.762	0.580	0.513	0.768	-	0.009
Ex4	0.004	0.000	0.042	0.039	0.009	-

Table 9.11b. Levene's equality of variance for weight data, by assemblage.

Refinement and shape

Although running one-way *ANOVA* on all refinement and shape attributes produced statistically significant inter-assemblage variation (p = < 0.000 in all cases), the results were unable to demonstrate a direct and statistically significant causal linkage between refinement and shape measures and the type of transmission actually employed. In an attempt to display the interaction between shape, refinement and transmission bias, Figure 9.15 plots the two main Roe shape and refinement ratios in a scatter and generates some observations which indicate or suggest associations that will be explored further by using evidence provided by the CVs, standard deviations and Levene's equality of variance (from the raw data), in each case. The observed findings were as follows:

Refinement

- There was a similarity in the achievement of $\frac{Th}{B}$ between Boxgrove and the TCP of Experiment 4 (Ex4).
- The poor $\frac{Th}{B}$ achievement by the Cuxton knappers, contrasted with the more refined ratios of the Experiment 3 (Ex3) TCP.

Shape

- The Experiment 3 (Ex3) TCP produced a grouping of the most pointed handaxes based on low $\frac{L1}{L}$ ratios, as a proportion of the entire Ex3 assemblage.
- However, there was a distinct and consistent $\frac{L1}{L}$ grouping by the Boxgrove knappers, compared to all other groups.

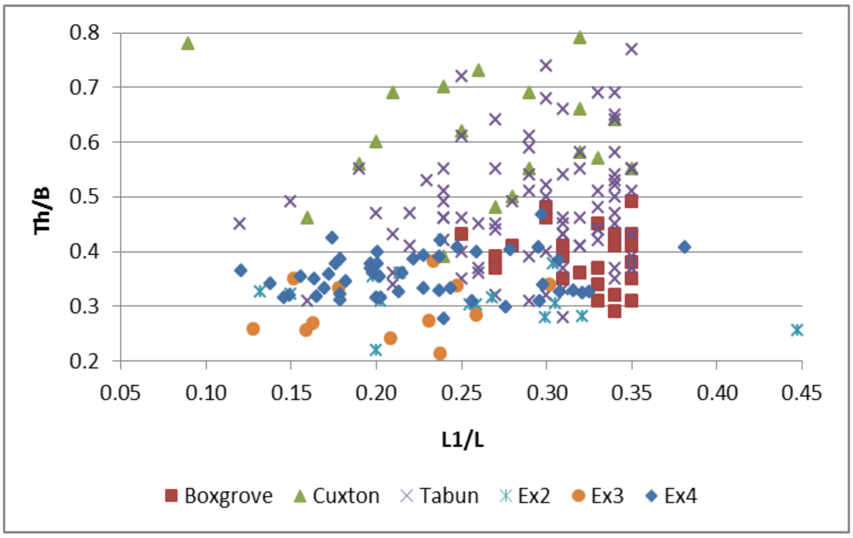


Figure 9.15. A shape and refinement scatterplot comparing all experimentally knapped handaxes with archaeological handaxes sourced from the ADS Acheulean biface database.

The use of CV brought several inter-assemblage relationships into relief. Firstly, it rationalised the seemingly crude refinement performance of the Cuxton knappers given by the scatter of Figure 9.15. Their $\frac{Th}{B}$ CV (0.179) compared favourably with that of Ex3 (0.177) and was better than that of Tabun (0.222), indicating that there was likely a consistency of knapping skill at Cuxton, directed towards a particular tool form, which may, or may not have been driven by raw material shape (Table 9.12a). That consistency was, however, tempered by the fact that Levene's equality of variance (Table 9.12b) failed to prove there was a significant difference between Cuxton and Tabun (p = 0.862), but did reposition the level of variation in the Ex3 assemblage as significantly different from that of Cuxton (p = 0.026), emphasising the positive role of cultural parenting. The previous association between Ex3 and handaxe refinement, demonstrated by the analysis presented in Chapter 7, was weakened here by the CV of 0.177 because all handaxes knapped were included in the sample, as opposed to solely the chosen forms, which represented the best target form matches passed through the TC, as a result of expert instruction from the cultural parent. When analysis was restricted to chosen forms only, the Ex3 CV dropped to 0.121, further reinforcing the role of one-to-one expert instruction, directed towards the achievement of a specific attribute, refinement, in this case.

The nature of the significant differences in $\frac{Th}{B}$ variation between the archaeological assemblages of Boxgrove and Cuxton (*p* = 0.04), and Boxgrove and Tabun (*p* = 0.03) (see Table 9.12b), was emphasised by the use of the CV (Boxgrove, CV = 0.140, Cuxton, CV = 0.179, Tabun, CV = 0.222) (Table 9.12a). The lower level of variation for Boxgrove was closer to that achieved by the knappers in Ex2 (CV = 0.135) and Ex4 (CV = 0.112). Whilst this similarity, from the perspective of the experimental knappers, may have been a product of the relatively thin and standardised nature of the perform porcelain cores (especially for the uninstructed end-state copying of the Ex2 transmission chain), it does emphasise the skilful nature of the Boxgrove knappers, who achieved comparative CV levels from non-standardised raw material. The level of skill and likelihood that there was a positive or direct form of cultural transmission operating at Boxgrove was further emphasised by the fact that although the assemblage used in this study was selected on the basis of a specific $\frac{L1}{L}$ ratio (section 9.8.1), the handaxes that comprise it were, in all likelihood, the result of palimpsest occupation which, provides an indication of how consistency of form was maintained and transmitted through and between different generations of knappers, at Boxgrove.

The variation between Ex4 $\frac{Th}{B}$ and all other assemblages, as highlighted by Levene's test, was significant (*p* = < 0.000) in all cases (Table 9.12b), likely indicating the specific nature of variation produced by many-to-one transmission, from a group of experienced peers. The use of CV and mean based analysis emphasised the nature of that variation. The Ex4 CV (0.112) was (as noted above) marginally lower than that of Boxgrove (0.140), as was standard deviation (0.04 and 0.054 respectively). Looking purely at standard deviation, Boxgrove was closest to Ex3 (0.054 and 0.052 respectively). However, analysis of the mean $\frac{Th}{B}$ +/- one standard deviation confirmed Boxgrove handaxes were closer to those of Ex4 than Ex2 or Ex3, in the range or spread of variation demonstrated by the knappers of each assemblage (Table 9.12a). Although this comparison of data does not align the achievement of the Ex4 knappers and by extension their TCP with any specific archaeological assemblage, it does indicate that the Boxgrove knappers demonstrated levels of knapping refinement that indicated the possible operation of an active/instructional form of cultural transmission such as vertical or oblique transmission.

Assemblage	*Count*	*Sum*	*Mean*	*Variance*	*Std. Dev.*	*Low*	*High*	*CV*
Boxgrove	24	9.34	0.389	0.003	0.054	0.335	0.444	0.140
Cuxton	19	11.54	0.607	0.012	0.109	0.499	0.716	0.179
Tabun	85	40.98	0.482	0.011	0.107	0.375	0.589	0.222
Ex2	14	4.31	0.308	0.002	0.041	0.266	0.349	0.135
Ex3	12	3.53	0.294	0.003	0.052	0.242	0.346	0.177
Ex4	48	17.08	0.356	0.002	0.040	0.316	0.396	0.112
Ex2 Chosen	8	2.41	0.301	0.002	0.040	0.261	0.341	0.133
Ex3 Chosen	7	2.01	0.287	0.001	0.035	0.252	0.321	0.121
Ex4 Chosen	6	2.11	0.351	0.002	0.047	0.304	0.399	0.134

Table 9.12a. CV, mean and standard deviation comparison of $\frac{Th}{B}$ refinement between Boxgrove handaxes and all handaxes from Experiments 2, 3 and 4.

	Boxgrove	Cuxton	Tabun	Ex2	Ex3	Ex4
Boxgrove	-	0.040	0.030	0.158	0.949	0.000
Cuxton	0.040	-	0.862	0.002	0.026	0.000
Tabun	0.030	0.862	-	0.002	0.036	0.000
Ex2	0.158	0.002	0.002	-	0.149	0.000
Ex3	0.949	0.026	0.036	0.149	-	0.000
Ex4	0.000	0.000	0.000	0.000	0.000	-

Table 9.12b. Levene's equality of variance for $\frac{Th}{B}$, by assemblage.

From a shape perspective ($\frac{L1}{L}$), the variation produced by the Boxgrove handaxes again demonstrated significant difference when compared to all other assemblages (Table 9.13a). This difference was interpreted in a positive light reflecting the consistency with which they had been knapped, by having the lowest $\frac{L1}{L}$ CV (0.092) and standard deviation (0.029) of all assemblages (Table

9.13b). The use of CV here further demonstrates the lack of ability to manage the pointedness of the handaxe form by the experimental knappers, in all groups.

	Boxgrove	Cuxton	Tabun	Ex2	Ex3	Ex4
Boxgrove	-	0.003	0.006	0.002	0.008	0.001
Cuxton	0.003	-	0.178	0.630	0.478	0.607
Tabun	0.006	0.178	-	0.055	0.857	0.274
Ex2	0.002	0.630	0.055	-	0.298	0.270
Ex3	0.008	0.478	0.857	0.298	-	0.659
Ex4	0.001	0.607	0.274	0.270	0.659	-

Table 9.13a. Levene's equality of variance for $\frac{L1}{L}$, by assemblage.

Assemblage	*Count*	*Sum*	*Mean*	*Variance*	*Std. Dev.*	*Low*	*High*	*CV*
Boxgrove	24	7.700	0.321	0.001	0.029	0.291	0.350	0.092
Cuxton	19	4.950	0.261	0.005	0.068	0.193	0.329	0.261
Tabun	85	24.690	0.290	0.003	0.052	0.239	0.342	0.179
Ex2	14	3.555	0.254	0.007	0.081	0.173	0.335	0.318
Ex3	12	2.501	0.208	0.003	0.052	0.156	0.261	0.251
Ex4	48	10.813	0.225	0.003	0.059	0.167	0.284	0.261

Table 9.13b. CV, mean and standard deviation comparison of $\frac{L1}{L}$ shape ratio between archaeological and experimentally knapped assemblages.

Table 9.14a provides a broader look at shape and dimensional CVs. The area based CVs send mixed messages, likely due to sample sizes being based on the chosen forms in Ex2 and Ex3 and the differing calculation methodology used by ADS and the ImageJ process used for the experimental assemblages in this study. However, when using the standardised measures, another consistent Boxgrove performance is demonstrated with a $\frac{B}{L}$ CV of 0.074, which, in combination with the $\frac{L1}{L}$ CV sits closer to the range of variation associated with perceptual limitation (discussed in Chapter 2), as opposed to the skill dependent levels of variation associated with a reductive technology such as flint knapping. The Boxgrove $\frac{B}{L}$ CV was also closest to that of Ex4 (0.112), when compared with all the experimentally knapped assemblages. In terms of statistical significance, Table 9.14b shows no significant difference between Boxgrove and the three experimental assemblages, but does between Tabun and Cuxton.

Assemblage	*Weight*	*Length*	*Breadth*	*B/L*	*Area*	*L1/L*
Boxgrove	0.335	0.152	0.140	0.074	0.272	0.092
Cuxton	0.720	0.284	0.210	0.158	0.492	0.261
Tabun	0.709	0.242	0.193	0.134	0.459	0.179
Ex2	0.241	0.107	0.083	0.135	0.087	0.318
Ex3	0.225	0.077	0.126	0.177	0.177	0.251
Ex4	0.179	0.089	0.096	0.112	0.151	0.261

Table 9.14a. Shape and dimensional CVs for archaeological and experimentally knapped assemblages.

	Boxgrove	Cuxton	Tabun	Ex2	Ex3	Ex4
Boxgrove	-	0.130	0.020	0.632	0.193	0.445
Cuxton	0.130	-	0.693	0.790	0.328	0.006
Tabun	0.020	0.693	-	0.300	0.171	0.000
Ex2	0.632	0.790	0.300	-	0.425	0.949
Ex3	0.193	0.328	0.171	0.425	-	0.287
Ex4	0.445	0.006	0.000	0.949	0.287	-

Table 9.14b. Levene's equality of variance for $\frac{B}{L}$, by assemblage.

The first hypothesis generated from these results is that cultural parenting from an expert knapper (or vertical transmission), over the duration of its existence, is able to produce strong results in terms of fidelity of copying and reproduction of refined and well-shaped handaxes - if that was the direction of its focus. Figure 9.12a shows Ex3 had the lowest mean $\frac{Th}{B}$ ratio (0.294) of all groups, but not the lowest CV because the cultural parent gave less direct refinement instruction on one of the two cores knapped by each TC member. When focusing purely on the chosen forms passed through the TCs, that ratio dropped to 0.287 and the CV to 0.121. This produced results even more reflective of the nature of the instruction provided by the cultural parent. Perhaps, more tellingly, standard deviation at 0.035 became lower than all other assemblages, emphasising the immediate impact of vertical transmission on increasing handaxe refinement; a conclusion also supported by the direct comparisons between Ex2, Ex3 and Ex4 as discussed in section 9.3 and 9.6.

Secondly, transmission bias related to the hypothesis that certain degrees of variation were permitted within a constrained artefact form (or conversely, certain attribute patterns were more rigidly governed than others), can be explored here with regard to the Tabun assemblage. Further inspection of the $\frac{Th}{B}$ data appears to conflict with the comment made by McPherron (2003) that refinement of the Tabun assemblages was (as discussed in section 9.8.1.2) fairly constant. Table 9.12 shows the CV for that attribute at 0.222 was higher than for all other assemblages, and standard deviation at 0.107 was almost identical to the reportedly roughly made handaxes of Cuxton (Tester, 1965). However, when considering the shape attributes highlighted in Table 9.14a, CV performance indicated more restrained knapping with less variation in all measures when compared to Cuxton and a lower $\frac{L1}{L}$ score than for all experimental assemblages. Here there are two possible inferences regarding the type of cultural transmission demonstrated by the Tabun assemblage. Firstly, as with Ex3 there could have been a specific focus by a cultural parent, on one attribute that was difficult to regulate when levels of skill were relatively low, $\frac{L1}{L}$ in this case, which, as shown by all the experimental data is difficult to maintain. On this basis, if transmission was vertical (as with Ex3), focus on the area of instruction would produce accurate transmission or a low CV in that area, at the expense of other attributes, in this case refinement or $\frac{Th}{B}$. The second conclusion could be that shape as defined by $\frac{L1}{L}$ was tightly constrained by the cultural group norm and enforced via oblique transmission where knapping instruction was given on a many-to-one basis. Refinement in this case was the attribute where variation was culturally permitted.

The uncertainty demonstrated by the above scenario illustrates the complexity of separating the signals of different types of cultural transmission from archaeological assemblages. As an extension of that issue, a third hypothesis is that the Boxgrove knappers, as those of Ex4, likely knapped in an environment where the majority of instruction and practice occurred in groups. This hypothesis was derived from the closeness of Ex4 results to those of Boxgrove, based on the initial interpretation of Figure 9.15, and the conclusion of Stout *et al* (2014) referencing the social context of knapping practice at Boxgrove. By extension, given the proximity of both sets of results, practice likely occurred not only in a group environment but also on a many-to-one basis, as in Ex4. This is the bias that occurred within the dynamic of the social group that (as discussed in Chapter 5 and section 9.8 above) likely resulted in the formation and maintenance of the group norms that became the foundation of handaxe production. In conflict with this idea, Figure 9.16 and Figure 9.17 both show that cumulative refinement and shape CV levels for Boxgrove were actually closest to those produced by the vertical transmission of the cultural parenting TCP of Ex3. However, within those cumulative similarities are examples where the CVs for specific attributes e.g. $\frac{B}{L}$ and $\frac{Th}{B}$ were respectively closest to or lower than those of the Boxgrove assemblage, thereby continuing to align the transmission bias with that of the many-to-one group knapping environment of Ex4.

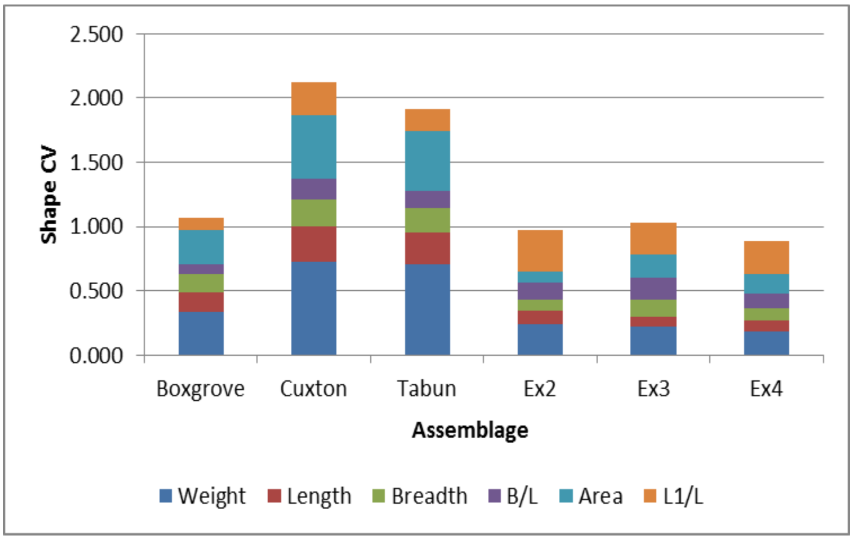


Figure 9.16. Cumulative shape CV levels by assemblage.

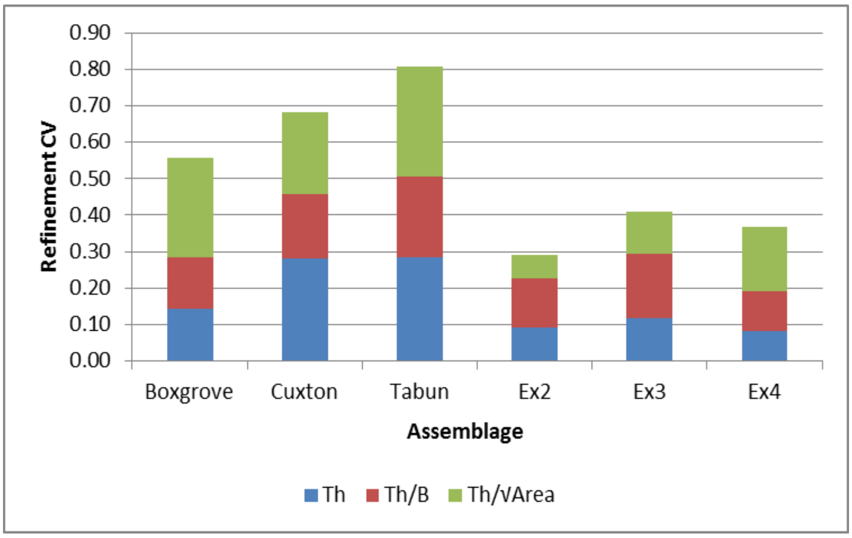


Figure 9.17. Cumulative refinement CV levels by assemblage.

The difficulty experienced when trying to align transmission bias and archaeological assemblage demonstrates that in reality, cultural transmission was likely a fluid process where differing biases occurred at different times within the lifecycle of each Palaeolithic group. The specific signal provided by the archaeology is likely to reflect the skill level and position of the knappers within that cycle, rather than the existence of a singular type of transmission bias. Further complexity is created when, as was the case with the archaeological pieces used in this analysis, the spatial and stratigraphic relationship between each handaxe in the assemblage is not known. That aside, the effect of differing cycles of transmission bias, in situations where population density was low and instances of inter-group contact rare, meant that wide fluctuations in skill level were probable. It is this dynamic that produced likely causes of variation, within the Acheulean handaxe template, that were experienced on a micro and macro-regional level, from the Middle Pleistocene on.

Chapter 10.

Conclusion

10.1.1 Summary

The introduction of this thesis stated that this is the first time a theory established in psychology, used for the exploration of how artefact form changes when subject to multiple generations of copying, has been applied to an archaeologically attested craft technique such as flint knapping, with the aim of demonstrating cultural change in a Darwinian framework. The primary hypothesis under consideration was that variation and/or conformity in lithic form was the product of socially generated copying biases and that these biases could, to differing degrees, determine the direction of cultural evolution. As sub-sets of that hypothesis, it was believed that variation would also be effected by skill level and human perceptual limitation. To address this hypothesis on the cultural evolution of lithic artefact form, the three objectives of the research design were achieved as follows.

- The development of a series of TC experiments to replicate possible modes of transmission in the Palaeolithic. This had to be done by overcoming two issues:
    - utilising a methodology that neutralised the likelihood that variation in artefact form could be attributed to differing raw material, and not cultural factors.
    - training enough participants to a level where they possessed enough knapping skill to produce meaningful results.
- The development of measurement and analysis techniques capable of capturing culturally created variation more effectively than currently established techniques.
- The creation of a methodology allowing comparison of experimentally created Acheulean variation with that discovered in archaeological

assemblages, to enable judgement to be made on the types of transmission used in the Acheulean of the Middle Pleistocene.

The issue of creating a homogenous raw material for the research programme was solved by developing the porcelain core technology. Training was conducted by using the skills of master-knapper and head PI (BB), and creating a research design that dovetailed with the instructional programme of the wider 'Learning to be Human' project. A more effective measurement and analysis technique was developed by evaluating the traditional metric based system of Roe (1968) and adding to it a more relevant suite of techniques involving new geometric measures of 3D shape, area based measures from pixel based imaging software and planform symmetry, also derived from imaging software. The series of four TC experiments was then conducted using the porcelain core technology, specified knapping training procedures and measurement/analysis techniques, to address the following questions.

Experiment 1: What was the effect on the evolution of blade form of differences in skill level and could any of that variation be attributed to perceptual limitation?

Experiment 2: What was the effect of unrestricted end-state copying (or horizontal transmission) on ovate and pointed handaxes, as they passed through a multi-generational transmission chain? This formed the base-line or null condition against which the other experiments were compared and was also used to evaluate the extent to which the two types of handaxe form could converge when not subject to a positive or restricting bias.

Experiment 3: What was the effect of one-to-one expert instruction from a cultural parent (or vertical transmission) on the form of pointed handaxes, as they passed through a transmission chain?

Experiment 4: What was the effect of many-to-one instruction from groups of experienced peers (or oblique transmission) on pointed handaxe form, as it passed through the transmission chain? And did knapping in groups produce a commonality of form or group norm through the generations of the transmission chain?

The aim of comparing the experimental assemblages with archaeological assemblages, to determine the type of transmission used in different examples of the Middle Pleistocene Acheulean was achieved by utilising the ADS Acheulean handaxe database. This produced artefacts from three distinct sites: Boxgrove, Cuxton and Tabun, each demonstrating clear differences in knapping style.

10.1.2 Main findings

With raw material and tool reduction neutralised as factors capable of accounting for variation in artefact form, conclusions drawn from the above research programme prove the following.

- Differentials in both skill level, and type of cultural bias possessed the ability to change artefact form as it was transmitted through multiple generations of copying. Such levels of change, due to limitations in skill level, were far in excess of those expected if perceptual limitation (i.e. random drift) was the sole driver of modification in artefact form.

- Lack of skill led to a cumulative breakdown in overall handaxe form, although the basic premise of the handaxe as a bifacially worked, symmetrical tool, remained throughout the TCs of all experiments, irrespective of transmission bias. Maintenance of symmetry, as a trait, was particularly strong. These factors likely account for the differential survival rates of handaxe attributes, demonstrated by the archaeological record, whilst also explaining the long-term survival of planform symmetry as a key and defining handaxe attribute.

- The importance of direct one-to-one teaching as a method for obtaining the level of skill necessary to maintain and transmit more complex attributes, such as handaxe refinement and the ability to produce invasive thinning flakes, was demonstrated by the vertical transmission of Experiment 3.

- Despite attribute changes from the initial target form, levels of variation in handaxe form could be constrained by the type transmission bias employed, especially where knapping took place in informal social groups and instruction was provided on a many-to-one basis - the conditions provided by the oblique transmission of Experiment 4.

- Variation produced by laboratory based transmission chain experiments was aligned with levels of variation produced from archaeological assemblages. On a culture evolutionary level, this means it is possible to broadly reconstruct the likely type of transmission bias that operated in the groups of Palaeolithic hunter-gatherers who produced certain assemblages of archaeological handaxes (or other lithic tool forms). The archaeological assemblage from Boxgrove demonstrated evidence of a positive form of cultural transmission, likely a combination of vertical and oblique transmission, as demonstrated by Experiments 3 and 4.

These results add weight to the value of cultural transmission and illustrate the ability of TC experiments to provide new and complimentary hypotheses that help to explain phenomenon such as the broad regional variations that existed within a tool form that was constrained, or remained fundamentally in stasis for over a million years. On a more specific level, the following points outline the key results, from each experiment in the series.

- Different levels of skill produced different artefact trajectories. The two blade based TCs of Experiment 1 demonstrated that blade form evolved in distinct ways, with achievement of target form varying according to the attributes each different skill level were able to achieve and thus transmit.

- In a reductive technology like knapping, form will change or degrade as it is transmitted in unregulated scenarios, especially in situations where level of knapping skill is rated at intermediate or lower. With this in mind, the Acheulean experiments demonstrated that the rate and type of change varied according to the type of transmission bias the TC was subjected to.

- Loss of refinement features was more prevalent than loss of shape based attributes, unless, as in Experiment 3, they were the specific focus of one-to-one instruction from an expert knapper.

- Given the general but differential loss of target form attributes throughout each of the TCs, the consistent survival of planform symmetry in all handaxe experiments, was surprising.

- The group or many-to-one teaching condition also demonstrated a loss of form, but in a manner that was more consistent than that produced by the other biases, indicating the possible operation of conformist bias that led to the production of smaller, narrower and thicker handaxes.

- Comparison of the experimental data with archaeological data from the ADS database produced mixed results. The Boxgrove assemblage demonstrated clear evidence of skill and consistency that had been created or constrained by a positive form of cultural transmission. The difficulty occurred in separating the signals of each type of bias and deciding whether the Boxgrove knapping performance was closest to that of one-to-one expert instruction (Experiment 3) or many-to-one group based knapping, with informal instruction from skilled peers (Experiment 4).

10.1.3 Experimental Overview

The research programme was conducted against a backdrop that required the participants to master the craft of stone knapping, which is essentially a reductive technology. In terms of copying lithic form, this means that once a removal of any kind is made from the artefact, it cannot subsequently be replaced in any way and any copying error cannot be directly reversed, as would be the case in an additive technology such as pottery production (Schillinger *et al,* 2014). The impact of any errors had to be accommodated or somehow rectified by continuing with, and modifying different aspects of the knapping process, all of which perpetuate the reductive process. Within this process, blade based Experiment 1 showed that the degree of variation within the assemblage of each knapper (illustrated by dimensional CVs generally in excess of 20.0), was substantial. Morphological changes to discrete attributes such as dorsal ridges and edge convergence also provided unexpected levels of inter-assemblage variation. The subsequent result on the chosen form transmitted throughout the course of each TC, indicated levels of variation far in excess of the range ascribed to perceptual limitation alone. Limited motor skill, operating within the constraints of a reductive technology was regarded as the main source of copying error. In terms of psychological theory surrounding changes to transmitted form, due to drift created by perceptual limitation, there is a need to consider level of expertise, especially in a reductive craft such as stone knapping, before attributing rates or ranges of change created by randomly generated variation. This applies not only to micro-evolutionary experiments conducted under laboratory conditions but ultimately to subsequent Darwinian interpretations of lithic material from archaeological contexts.

In terms of comparing the assemblages and transmitted forms produced by the lesser and more skilled TCs, the assumptions of the neutral model, that there would be no difference between the output of the two transmission chains and that there would be no difference in the variation between types of attribute, were not supported. TC1 and TC2 had distinct trajectories; the more skilled knappers of TC1 were better able to control blade length and, in addition, elected to pass that trait on in preference to others. The role of motor skill was further emphasised with regard to attribute variation, where the attributes with smaller dimensions showed proportionally greater variance, further indicating the greater levels of skill required to accurately reproduce and subsequently transmit certain attributes, over others. The lack of, and relative difference in skill level between the two TCs of Experiment 1 both created culture evolutionary errors, which caused differences in the way lithic form mutated and changed, over multiple generations of copying. The transmission of variation as a result of skill related copying error became a recurrent theme throughout the remainder of the programme, and one which appeared to be effected differently, according to the type of transmission bias used in each experiment.

The overall trend demonstrated by the different TCs of Experiments 2, 3 and 4 was one of progressive movement away from the form of the base or original target form handaxe. The most surprising result was the consistent survival of planform symmetry across all the Acheulean experiments. These patterns of attribute loss and preservation were (as stated above) tempered by the differing types of variation created by changing the nature of the transmission bias in each of the experimental conditions. The uninstructed end-state copying of Experiment 2 resulted in a transmission of form where the extremities that defined the original pointed or ovate typological classification of the handaxe were lost. The result of this process was the formation of a more cordiform handaxe. The emergence of this almost default handaxe shape was likely a result of the fact that none of the TC members were expert or master knappers with skill levels sufficient enough to accurately manage multiple attributes simultaneously. However, when subject to the heavy scaffolding provided by the one-to-one teaching condition of Experiment 3, the most difficult task of biface thinning was achieved to a high level and was maintained without loss of handaxe size, but with some loss of symmetry. This conflicting result was caused by the increased focus the intermediate knapper was directing towards the demanding thinning task, as a direct result of the instruction from the cultural parent. With attention directed towards thinning, the more usual and perhaps achievable trait of symmetry survived less well in an environment where other, usually more problematic traits, were now competing for attention. Conversely (without cultural parenting), in Experiments 2 and 4, symmetry was maintained and survived as a trait, but at the expense of handaxe size and refinement.

In Experiment 4, the trend towards a form that became progressively thicker and smaller was verified by $\frac{Th}{\sqrt{ADVA}}$ measures, at the same time as becoming less pointed. Use of *ANOVA* on the Experiment 4 results also revealed indications of inter-generational differences, often forming away from the attribute patterns of the target form for each group. These were (again) likely the result of skill related issues, rather than the deliberate formation of (statistically significant) group norms, as a result of knapping as part of a peer group in a many-to-one TCP. In this context, skill differential, in all transmission scenarios, can be viewed as a key factor in the formation of attribute variation and, as discussed in Chapter 5, indicates that different bias types were likely in operation at different points in the lifecycle of each knapper or knapping group, as was the case for the participants of Experiments 2, 3 and 4. Against a background of low population density and small hominin group sizes, instruction in the Middle Pleistocene may not always have been provided by an expert knapper, even under circumstances of vertical transmission, or even from a group of skilled peers (in an oblique fashion). These factors likely resulted in frequent loss of skilled knappers who (as this research programme has revealed) are not always readily available. In this context, the acts of copying and transmission may have experienced periods where the knapper available to copy from, possessed only limited ability (as in Experiment 2), which would have resulted in the maintenance of basic tool form only; a situation leaving typological extremities to be eroded and only dominant attributes such as symmetry, to be transmitted.

Temporal losses of skilled personnel (because of death or group budding) and the subsequent time-lag involved in the redevelopment of skill through practice or the acquisition of new group members, are factors also likely responsible for stasis in basic tool form, subject only to idiosyncratic levels of attribute variation. Where skill does develop and can be transmitted in a many-to-one environment (as in Experiment 4), the potential does exist for the formation of clusters of well-produced or similar forms (see symmetry and refinement in Generation 5,

Figure 8.23), the attribute patterns of which could become a group norm, maintained by the dynamic of the many-to-one instruction protocol. For this to occur, a consistency of skill level has to survive and be transmitted over multiple generations. On an archaeological basis, the outcome of this process could result in the levels of distinct regional variation seen in handaxe form (within the broad tool construct) seen on a macro-regional basis, as illustrated by Wynn & Tierson (1990). Paradoxically, it is the existence of fragile and low density population levels that allows for the existence of vertical, horizontal and oblique transmission biases all of which, on some level, could be used to interpret the archaeological record of the Middle Pleistocene and offer explanation for stasis throughout the Acheulean.

The difficulty experienced when trying to align results from the experimentally produced transmission biases with archaeological assemblages from the ADS database (section 9.8.1), was illustrated by the closeness of results between the assemblages from Boxgrove and both the cultural parenting (vertical transmission) of Experiment 3 and the many-to-one (oblique transmission) of Experiment 4. This demonstrated that in reality, cultural transmission did not occur in discrete packages, but instead was likely a fluid process where differing biases occurred at different times within the lifecycle of each Palaeolithic group. The specific signal provided by archaeological assemblages is likely to reflect the skill level and position of the knappers within that cycle, rather than the existence of a singular type of transmission bias. Despite this restriction, the use of transmission chains to assess experimentally produced variation as a result of differing transmission biases, maintains the ability to produce new and enhanced ideas on the nature of the cultural transmission process in Middle Pleistocene groups of *Homo heidelbergensis,* and reinforces the importance of teaching in the culture evolutionary process.

10.2 Overcoming methodological issues

To ensure that variation in lithic form produced by knapping in transmission chains was solely the result of cultural factors such as the type of transmission bias, or level of skill related to bio-mechanical management of the knapping process, required that raw material be controlled for as effectively as possible. Other experimental work in lithic technology attempted to overcome the problem of heterogeneous raw material in a variety of ways, all of which only partially dealt with the problem (section 2.1.7). Being part of the ‘Learning to be Human’ project allowed the porcelain preform core technology, developed by the wider project, to be adapted and used in this research to produce homogenous preform blade cores and handaxe blanks. This ensured that each knapper or knapping generation, in each transmission chain, was using a moulded preform core that conchoidally fractured in the same manner as flint and was as similar in shape, size and density as was reasonably practicable. On this basis, the issue of providing standardised raw material was overcome, ensuring that the changing form of the lithic artefacts throughout the TCs of each experiment was directly attributable to the TCP employed.

From the initial measurement of the Experiment 1 blade assemblages, it became apparent that standard use of dimensional metrics was not enough to effectively capture inter and intra-generational variability and overall changes in form. Despite the ability of the Roe (1968) metrical system to identify the loss of pointed handaxe form, and demonstrate movement towards a more cordiform shape in Experiment 2, the same was true for all the handaxe experiments. To this end and in the first instance, the coefficient of variation (Eerkens & Bettinger, 2001; Roux, 2003) was used to allow for meaningful comparison of basic metrical data. Following this, a system of measurement was developed (Chapter 3) that went beyond trying to capture form change solely by taking a series of two dimensional measures, between two points (generally the largest dimension) along a variable attribute (i.e. length, width, thickness) and creating a ratio, to one which considered the artefact as a three dimensional object. At the most basic level, for both blades and handaxes, this meant creating taper measures that were adjusted for length, followed by the creation of a measure that represented the 3D Euclidean distance travelled by each chosen form, from the base target form of each TC. For Experiments 2 – 4, imaging software (ImageJ) was adapted and employed to take area based measures (cm^2), providing better indications of actual change to handaxe size and residual cortex area. Empirical measurement of handaxe symmetry was also included in the evaluation process by utilising Flip Test (Hardaker & Dunn, 2005), another piece of image based software. These new measures, in combination with Roe's (1968) system of metrics and ratio based analysis, enabled a more inclusive and meaningful measure of size and shape change to be made, as a result of each TCP employed.

Management of TCP enabled the creation of different types of bias or socially constructed knapping conditions in a laboratory environment. This was critical for experimentation with different micro-evolutionary conditions and allowed for the objective comparison of levels of inter and intra-generational variation. Developing the compound model shown in Figure 2.9 (and discussed in section 2.2.6) facilitated the design of the TCPs used in this thesis. Experiments 1 and 2 used standard single member linear TCs to explore levels of artefact variation produced by using end-state copying in the context of horizontal transmission. Experiment 3 explored one-to-one instruction from a cultural parent in the context of vertical transmission. Ideally, in this TCP, each generation would be a closed group. However, due to severe restrictions on the number of people who could enact the role of cultural parent, the design required modification; the cultural parent remained the same throughout the entire duration of the TC, whilst the instructed knapper was different in each generation. Experiment 4 required the most development, over and above the standard solutions presented by Figure 2.9. To explore the concept of learning in a peer group environment involved informal knapping instruction being given on a many-to-one basis. In this context (again), because of restrictions on the numbers of skilled knappers, the three group members providing instruction remained the same throughout the TC, whilst the instructed knapper of intermediate ability changed in each generation. This provided an oblique, group based mode of cultural transmission. In this way, the TCP of each experiment was developed to provide micro-evolutionary representations of three distinct types of cultural evolution (Table 9.10).

In addition to providing solutions to the issues of raw material homogeneity, effective measurement systems and the development of suitable TCPs, as discussed above, the exploratory and largely theoretical nature of this project meant that the research remained essentially self-contained. In this respect, subject to time and budgetary constraint, the results produced from the TCPs of each experiment could not, in a bespoke manner, be tested against or compared with any archaeological assemblages. To overcome this problem and help validate the experimental data, the ADS Acheulean handaxe database (Marshall *et al,* 2002) was used. Interrogating the ADS database, subject to appropriate filters (section 9.8.1), provided three suitable handaxe assemblages, one each from the Middle Pleistocene sites of Boxgrove, Cuxton and Tabun. The Boxgrove assemblage provided signals reflective of variation produced under the experimental TCPs of both Experiment 3 (cultural parenting) and Experiment 4 (many-to-one instruction). Although not aligning solely with a single mode of cultural transmission, this result does indicate the positive influence of teaching in the knapping process. The confined levels of attribute variation within the assemblage also support theories advanced for the high levels of skill demonstrated at Boxgrove (Iovita & McPherron, 2011; Roberts & Parfitt, 1999) and the likelihood that in terms of cultural transmission, knapping occurred in a socially defined context (Stout *et al,* 2014). That context although likely group based, could possibly have included aspects of both oblique (many-to-one) and vertical (cultural parenting) transmission.

10.3 Limitations of the research design

The most overriding issue in all experiments conducted as part of this thesis was that of limited sample size. In some cases this has restricted the depth and statistical significance of the results and therefore the manner in which they can be interpreted (section 6.5, for example). It has also restricted the running of parallel TCs to test the outcome of the same TCP, multiple times. The reason behind this issue is inherent in all craft based experiments, particularly stone knapping; it is a Palaeolithic skill and as such it is virtually extinct, with few skilled contemporary practitioners. This is compounded by the fact that training enough novice knappers to the level where they can effectively participate in lithic based experiments, particularly transmission chains, is a long-term commitment spanning several years. The ‘Learning to be Human’ project has delivered that opportunity by providing access to enough trained knappers, to make the experiments in this thesis function. However, it should be borne in mind that even with laboratory based, micro-evolutionary experiments, testing TCPs with multiple chains and having longer TCs with more generations per chain, will likely produce results that are more robust in nature.

The results produced from the archaeological assemblages generated by the ADS data base, although meeting the stated metrical criteria (section 9.8.1 onwards), making them suitable for comparison with the experimental data, do have their limitations. It is likely that they came from different assemblages and as such, each set of data (archaeological and experimental) can only be compared as a whole. In terms of looking at cultural transmission on an inter-generational basis, without knowing the stratigraphic relationship between the handaxes of each archaeological assemblage, it is impossible to make any more detailed inferences regarding the types of transmission employed. This is likely another contributory factor behind the mixed signals provided by the Boxgrove assemblage when comparing its levels of variation with those produced by the TCPs of Experiments 3 and 4 (section 9.8.1.3). With this in mind, for interpretation of archaeological assemblages to work at a high resolution, it is important that the relationship between the pieces in the assemblage is understood.

Interpreting archaeological assemblages and inferring modes of cultural transmission through comparison with experimentally produced assemblages, although possible, faces an additional issue. Once performed, the analysis and its conclusions are difficult to validate against the archaeological record, as there is no evidence of the biases actually used in the Acheulean. However, as this largely a circular relationship, it further underlines the importance of the reconstructive process, which can only be achieved via experimentation with the differing types of cultural transmission and their likely effect on artefact form.

10.4 Future directions of research into cultural transmission

Research conducted as part of this thesis has extended the boundaries of both transmission chain theory and research into lithic technology, specifically that of the Acheulean record. The following considers those areas separately and lists the broader achievements and progress made under each respective research area.

Transmission chain theory

- The use of a real craft technique, in the form of stone-knapping, moves TC theory away from a focus solely on tasks constructed and performed in a theoretical vacuum.

- It marks the start of testing different craft based techniques e.g. knapping, pottery production or metallurgy, in a Darwinian framework, with the aim of establishing degrees or ranges of culturally transmitted variation which may be the product of skill related factors or perceptual limitation.

- As knapping is a reductive technology, as opposed to additive or constructive, production of lithic artefacts in transmission chains offers a new area of theory for the discipline to explore.

The Acheulean record

- TC experimentation with lithic artefacts has opened up a new area of research on variation in the archaeological record of the Acheulean, which is able to complement the traditional areas of raw material, cognitive limitation and demographic factors.

- It presents the possibility that the emergence of new lithic form or the constraint of variation within a conservative tool form, like the Acheulean handaxe, can be tested over multiple generations of knapping. The results can then be compared with archaeological assemblages, in a way not previously possible, when knapping experiments were limited solely to single bouts of copying.

- Focus on a TCP where the objective is to make an exact copy of the target form handaxe does offer a pure test of skill and how each knapper manages the biomechanical aspects of knapping. However, to advance the use of TCP, to test Acheulean handaxe form using a more pragmatic, Middle Pleistocene approach, a more functional aspect of tool production needs to be built into the experimental design. This would allow traditional design or functional aspects to be tested, providing more depth to comparisons made between assemblages knapped in TCs with those from the archaeological record.

- The addition to the TCP of replicating functional requirements would allow the transmission of skill in the Acheulean and how that is represented in the archaeological record, to be viewed and tested from the perspective of an established factor in explaining archaeological variation.

Based on the specific results of each experiment, together with the comparison with archaeological assemblages and the broader overall achievement or contribution to the specific fields of research (above), the consistent theme running through the blade and handaxe experiments conducted as part of this thesis is that of skill, and how influential it is as a driver in the culture evolutionary process. In terms of producing attribute variation in a reductive technology like stone knapping, differentials in skill level have the ability to produce changes more abruptly, and far in excess of the levels allocated to perceptual limitation and random drift alone. In this respect, possessing the relevant levels of skill to effectively create and manage culturally produced biases, as part of an experimental TCP, strongly dictates the sample sizes available to transmission chain experiments. With regard to furthering our understanding of transmission chain theory, outside of lithic technology, the issue of increasing sample sizes could be overcome by changing the craft medium used. There are far more skilled potters than stone knappers, so in this respect, the culture evolutionary process surrounding issues of ceramic production in the Neolithic would represent an achievable task for the further development of transmission chain theory, in a more statistically robust environment.

Recent studies that have tried to stay within the realms of lithic technology (specifically the Acheulean), have tested perceptual limitation using images of a handaxe presented on an iPad (Kempe *et al,* 2012), and levels of copying error in reductive versus additive material traditions, by copying handaxe form on a block of plasticine (Schillinger *et al,* 2014). Here, participants were asked to shape the handaxe by using a knife to remove (or add back) plasticine as part of the copying process. These approaches may (to some extent) circumvent the issues of sample size, but they do not deal with the central issue of experimental work in lithic technology related to copying error, that of developing, utilising and testing actual knapping skill and the effect it has on the culture evolutionary process.

If practising the craft of stone knapping is to remain at the centre of experiments on copying error and cultural transmission, then movement towards testing a more consistent technology or lithic tradition may provide a relevant area of research. The standardised nature of Upper Palaeolithic tool kits or Palaeo-Indian arrow heads where there is archaeological evidence of not only regional variation, but also variation linked to temporal progression, would provide great scope for the testing of skill, transmission bias and drift related theories. The added advantage here is that cognitively and bio-mechanically, the experimental data would be produced by the same species (*Homo sapiens*), as the archaeological data.

In contexts where the evolutionary trajectories of lithic technologies in the archaeological record cover periods spanning many generations, over several millennia, computer simulation could be used to bridge the temporal gap. This would not remove the physical practice of knapping or the issue of skill in lithic technology from the research programme. It would, in fact, remain central to its success as the ranges of attribute variation linked to both drift and skill, on a generational basis, would be derived from a base of humanly knapped artefacts. Those ranges would then be used to model and bootstrap the data according to the hypothesis of each research question. In this context, for example, the drift related theories of projectile point evolution between North and South America presented by Morrow & Morrow (1999) and discussed in Chapter 2, could be tested with experimentally produced data. This approach (using experimentally knapped lithic data as its basis) could ultimately be used with population density models, such as that presented by Powell *et al* (2009) and then, as discussed in Chapter 5, related to stasis in, or the disappearance of and reinvention of certain tool forms, variation in trait patterns or the production of macro-regional traditions in lithic artefact production.

From the perspective of excavation, as discussed in sections 9.8.1.3 and 10.3 (above), not knowing the true relationship between the pieces in most archaeological assemblages is a drawback to the process of inferring the operation of particular transmission biases and/or wider culture evolutionary movement. To help negate this problem, the excavation process and methodology could be defined by the need to identify the cultural transmission process. This is especially relevant where sites offer the opportunity of long sequences, and where archaeological integrity is relatively high, due to acceptable levels of taphonomic process. If the spatial (horizontal) and stratigraphic (vertical) relationship between each piece is recorded, the problems encountered with the ADS data will be minimised and identifying generations of artefacts (according to predefined criteria/attribute patterns) may become a reality. In turn, this will allow variation in generations of temporally discrete archaeological assemblages to be compared with generations of experimentally produced assemblages, produced under the constraints of differing modes of transmission bias.

The methodology and evidence provided by this thesis, combined with the issues discussed under the heading of ‘Future directions of research …’ provide extensive evidence and opportunity for the inclusion of skill and cultural transmission as key drivers in the creation of variation or stasis in lithic artefact form. Traditional factors accounting for variation such as raw material, reduction and resharpening, and more recently demographic issues of population density, undoubtedly have a role to play in the process. However, it does seem that they are more likely conduits along which culture evolutionary processes operate, with transmission biases acting as the mechanisms that provide the style, level and speed of artefact variation adopted, along with its degree of longevity or eventual survival.

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Appendices

Appendix 1: Comparison of significance levels derived from R^2 and the Mann-Kendall tau test

	Figure	Attribute	R^2	*p* value	Kendall's τ	*p* value	Change
Experiment 1	4.2	Thickness	0.6853	0.0420	0.733	0.056	
	4.2	Width	0.6659	0.0480	0.600	0.136	*
Experiment 2	6.3	Length	0.8844	0.0002	0.889	0.000	
	6.6	T1/L	0.6065	0.0450	0.556	0.045	
	6.9	B/L (TC1)	0.6146	0.0200	-0.643	0.031	
	6.9	B/L (TC2)	0.6290	0.0100	0.722	0.006	
	6.9	B1/B2 (TC2)	0.5808	0.0170	0.556	0.045	
	6.13	B1/B2 (TC2)	0.5808	0.0170	0.556	0.045	
	6.16b	3D Euclidean	0.8684	0.0002	0.889	0.000	
Experiment 3	7.2	Breadth	0.7522	0.0050	0.643	0.031	
	7.8	B/L	0.6715	0.0130	0.714	0.014	
	7.10	Weight	0.6728	0.0130	0.571	0.061	
	7.11	3D Euclidean	0.5542	0.0340	0.571	0.061	
	7.14	*ADVA*	0.6072	0.0200	0.429	0.179	*
Experiment 4	8.2	Length	0.6746	0.0230	-0.683	0.048	
	8.2	Breadth	0.7978	0.0068	-0.789	0.023	
	8.4a	Th/B	0.6637	0.0200	0.524	0.136	*
	8.4a	T1/L	0.5989	0.0400	0.619	0.069	*
	8.8	B/L	0.7960	0.0170	-0.733	0.056	
	8.9	Weight	0.5641	0.0520	-0.524	0.136	*
	8.10	3D Euclidean	0.8121	0.0056	0.905	0.003	
	8.14	*ADVA*	0.8487	0.0032	-0.810	0.011	
	8.16a	Th/√ADVA	0.7272	0.0150	0.619	0.069	*

Appendix 2: Table 1

TC1K1	Parallel edges			Convergent to point from 2/3 length			Point form			Total
	Count	% v	% h	Count	% v	% h	Count	% v	% h	
Central Ridge	12	66.7	63.2	6	75.0	31.6	1	50.0	5.3	19
2 Lateral Ridges	3	16.7	100.0	0	0.0	0.0	0	0.0	0.0	3
Other Ridge	3	16.7	50.0	2	25.0	33.3	1	50.0	16.7	6
Total	18			8			2			28
Achieved tgt %	43									

TC1K2	Parallel edges			Convergent to point from 2/3 length			Point form			Total
	Count	% v	% h	Count	% v	% h	Count	% v	% h	
Central Ridge	12	57.1	50.0	10	55.6	41.7	2	66.7	8.3	24
2 Lateral Ridges	4	19.0	66.7	2	11.1	33.3	0	0.0	0.0	6
Other Ridge	5	23.8	41.7	6	33.3	50.0	1	33.3	8.3	12
Total	21			18			3			42
Achieved tgt %	24									

TC1K3	Parallel edges			Convergent to point from 2/3 length			Point form			Total
	Count	% v	% h	Count	% v	% h	Count	% v	% h	
Central Ridge	6	28.6	100.0	0	0.0	0.0	0	0.0	0.0	6
2 Lateral Ridges	9	42.9	81.8	1	33.3	9.1	1	100.0	9.1	11
Other Ridge	6	28.6	75.0	2	66.7	25.0	0	0.0	0.0	8
Total	21			3			1			25
Achieved tgt %	24									

TC1K4	Parallel edges			Convergent to point from 2/3 length			Point form			Total
	Count	% v	% h	Count	% v	% h	Count	% v	% h	
Central Ridge	14	42.4	70.0	3	60.0	15.0	3	30.0	15.0	20
2 Lateral Ridges	9	27.3	100.0	0	0.0	0.0	0	0.0	0.0	9
Other Ridge	10	30.3	52.6	2	40.0	10.5	7	70.0	36.8	19
Total	33			5			10			48
Achieved tgt %	0									

TC1K5	Parallel edges			Convergent to point from 2/3 length			Point form			Total
	Count	% v	% h	Count	% v	% h	Count	% v	% h	
Central Ridge	11	40.7	84.6	0	0.0	0.0	2	66.7	15.4	13
2 Lateral Ridges	5	18.5	71.4	1	16.7	14.3	1	33.3	14.3	7
Other Ridge	11	40.7	68.8	5	83.3	31.3	0	0.0	0.0	16
Total	27			6			3			36
Achieved tgt %	0									

TC1K6	Parallel edges			Convergent to point from 2/3 length			Point form			Total
	Count	% v	% h	Count	% v	% h	Count	% v	% h	
Central Ridge	19	40.4	82.6	1	20.0	4.3	3	60.0	13.0	23
2 Lateral Ridges	9	19.1	90.0	0	0.0	0.0	1	20.0	10.0	10
Other Ridge	19	40.4	79.2	4	80.0	16.7	1	20.0	4.2	24
Total	47			5			5			57

Table 1. Co-occurrence matrix of non-metric attributes by knapper for TC1. Shaded areas represent the combination of non-metric target form attributes for each knapper in the TC.

Appendix 2: Table 2

TC2K1	Parallel edges			Convergent to point from 2/3 length			Point form			Total
	Count	% v	% h	Count	% v	% h	Count	% v	% h	
Central Ridge	22	57.9	91.7	1	50.0	4.2	1	33.3	4.2	24
2 Lateral Ridges	4	10.5	100.0	0	0.0	0.0	0	0.0	0.0	4
Other Ridge	12	31.6	80.0	1	50.0	6.7	2	66.7	13.3	15
Total	38			2			3			43
Achieved tgt %	51									

TC2K2	Parallel edges			Convergent to point from 2/3 length			Point form			Total
	Count	% v	% h	Count	% v	% h	Count	% v	% h	
Central Ridge	16	51.6	84.2	3	100.0	15.8	0	0	0.0	19
2 Lateral Ridges	1	3.2	100.0	0	0.0	0.0	0	0	0.0	1
Other Ridge	14	45.2	100.0	0	0.0	0.0	0	0	0.0	14
Total	31			3			0			34
Achieved tgt %	47									

TC2K3	Parallel edges			Convergent to point from 2/3 length			Point form			Total
	Count	% v	% h	Count	% v	% h	Count	% v	% h	
Central Ridge	5	20.8	50.0	4	100.0	40.0	1	100.0	10.0	10
2 Lateral Ridges	1	4.2	100.0	0	0.0	0.0	0	0.0	0.0	1
Other Ridge	18	75.0	100.0	0	0.0	0.0	0	0.0	0.0	18
Total	24			4			1			29
Achieved tgt %	17									

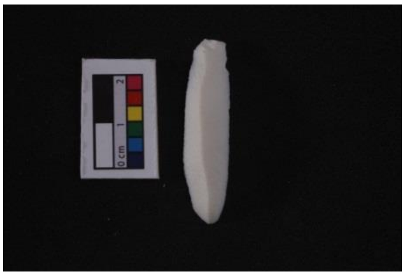
TC2K4	Parallel edges			Convergent to point from 2/3 length			Point form			Total
	Count	% v	% h	Count	% v	% h	Count	% v	% h	
Central Ridge	7	58.3	63.6	1	100.0	9.1	3	60.0	27.3	11
2 Lateral Ridges	1	8.3	100.0	0	0.0	0.0	0	0.0	0.0	1
Other Ridge	4	33.3	66.7	0	0.0	0.0	2	40.0	33.3	6
Total	12			1			5			18
Achieved tgt %	17									

TC2K5	Parallel edges			Convergent to point from 2/3 length			Point form			Total
	Count	% v	% h	Count	% v	% h	Count	% v	% h	
Central Ridge	16	45.7	94.1	0	0.0	0.0	1	100.0	5.9	17
2 Lateral Ridges	1	2.9	100.0	0	0.0	0.0	0	0.0	0.0	1
Other Ridge	18	51.4	85.7	3	100.0	14.3	0	0.0	0.0	21
Total	35			3			1			39
Achieved tgt %	0									

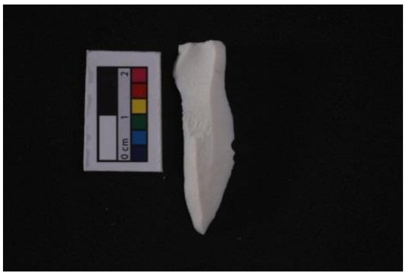
Table 2. Co-occurrence matrix of non-metric attributes by knapper for TC2. Shaded areas represent the combination of non-metric target form attributes for each knapper in the TC.

Appendix 3: Chosen Form Blades by Transmission Chain

Transmission Chain 1

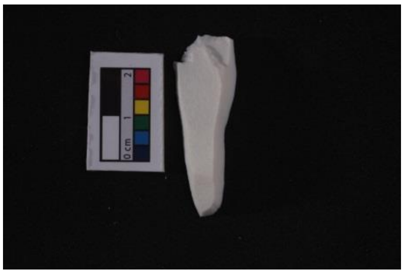


Base target form



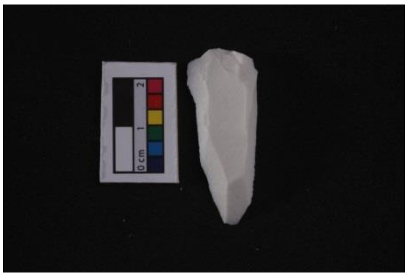
Knapper 1 chosen form

Knapper 2 chosen form

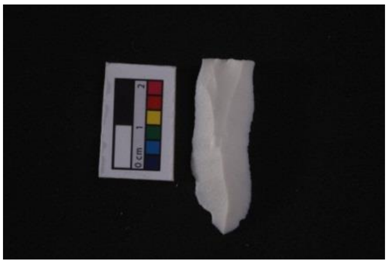


Knapper 3 chosen form

Knapper 4 chosen form



Knapper 5 chosen form

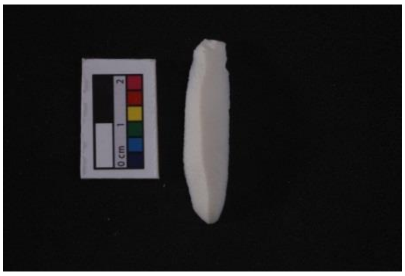


Knapper 6 chosen form

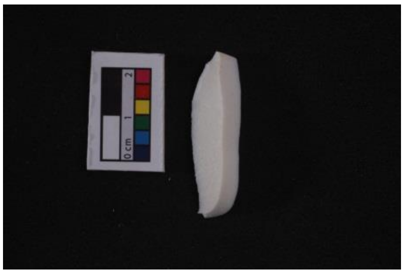
All photographs: S. Page

Appendix 3: Chosen Form Blades by Transmission Chain

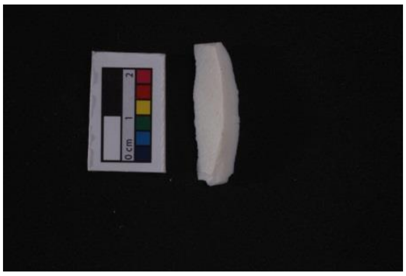
Transmission Chain 2



Base target form

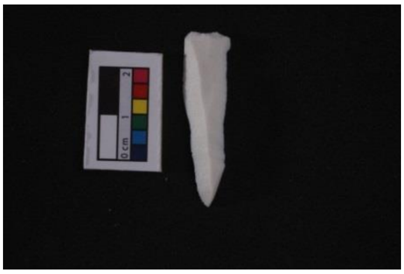


Knapper 1 chosen form

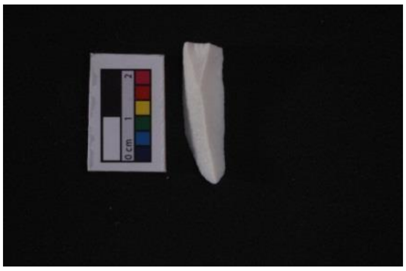


Knapper 2 chosen form

Knapper 3 chosen form



Knapper 4 chosen form

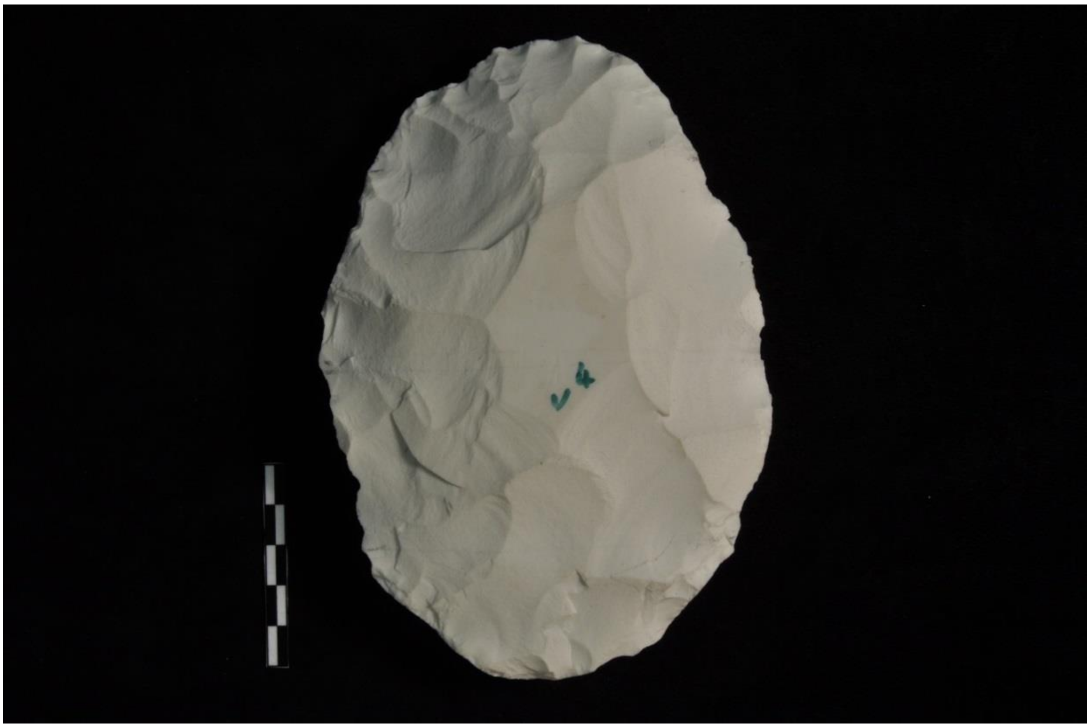


Knapper 5 chosen form

All photographs: S. Page

Appendix 4: Experiment 2 TC1 chosen form ovate handaxes

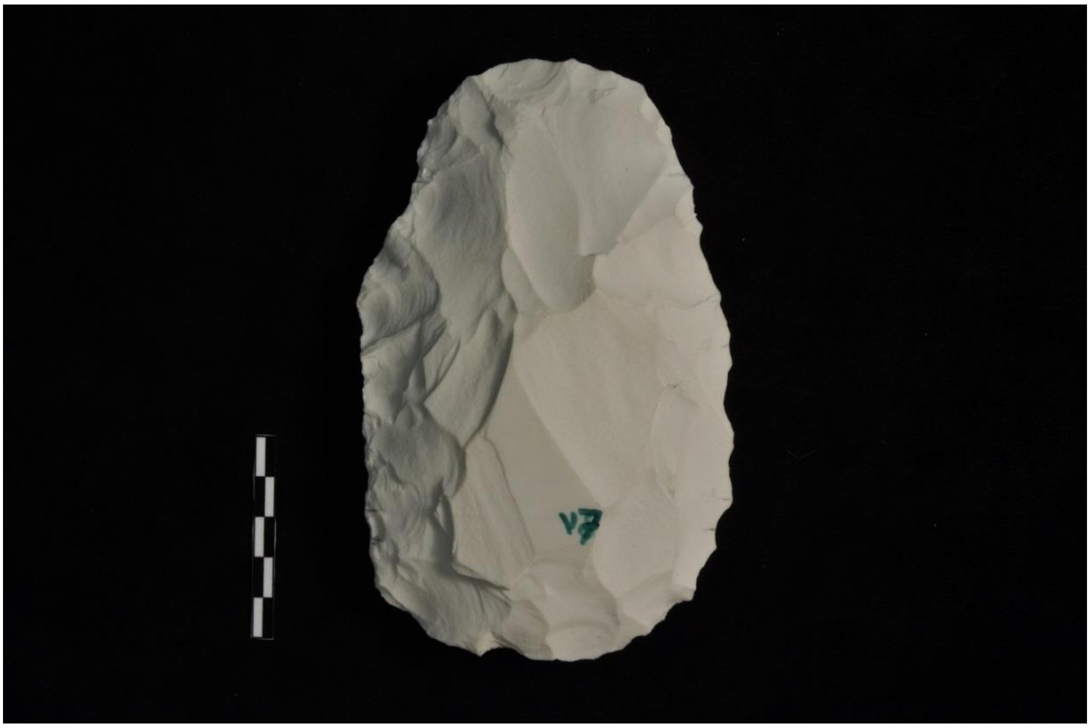
Knapper 1 chosen form ovate handaxe



Knapper 2 chosen form ovate handaxe

Photographs: S. Page

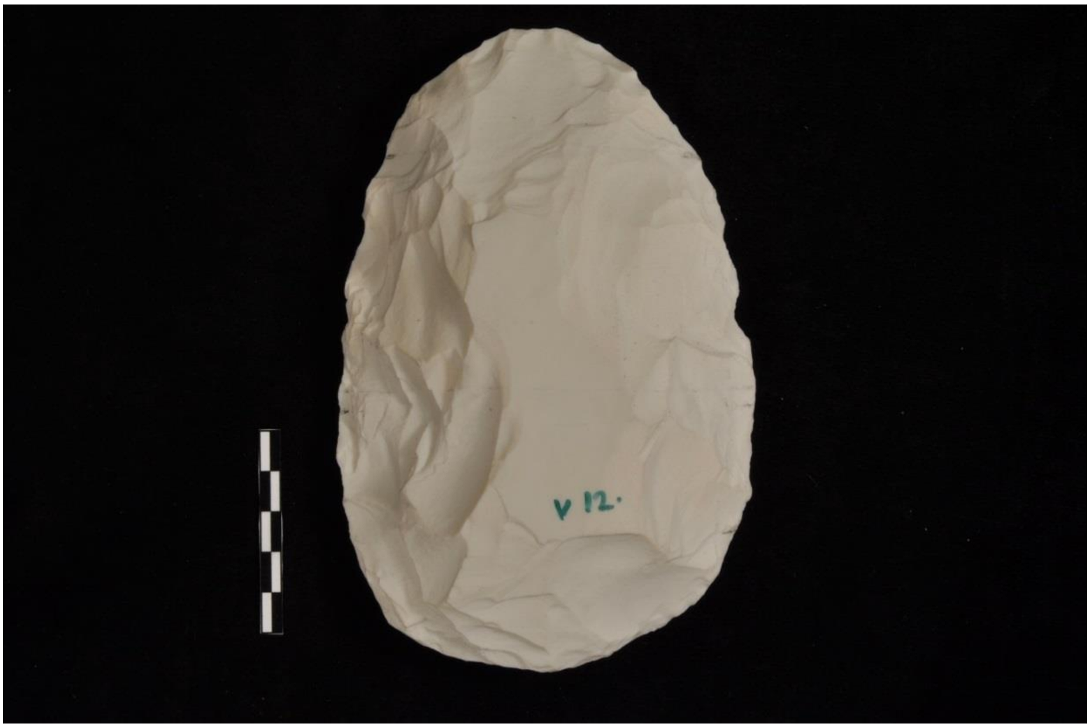
Knapper 3 chosen form ovate handaxe



Knapper 4 chosen form ovate handaxe

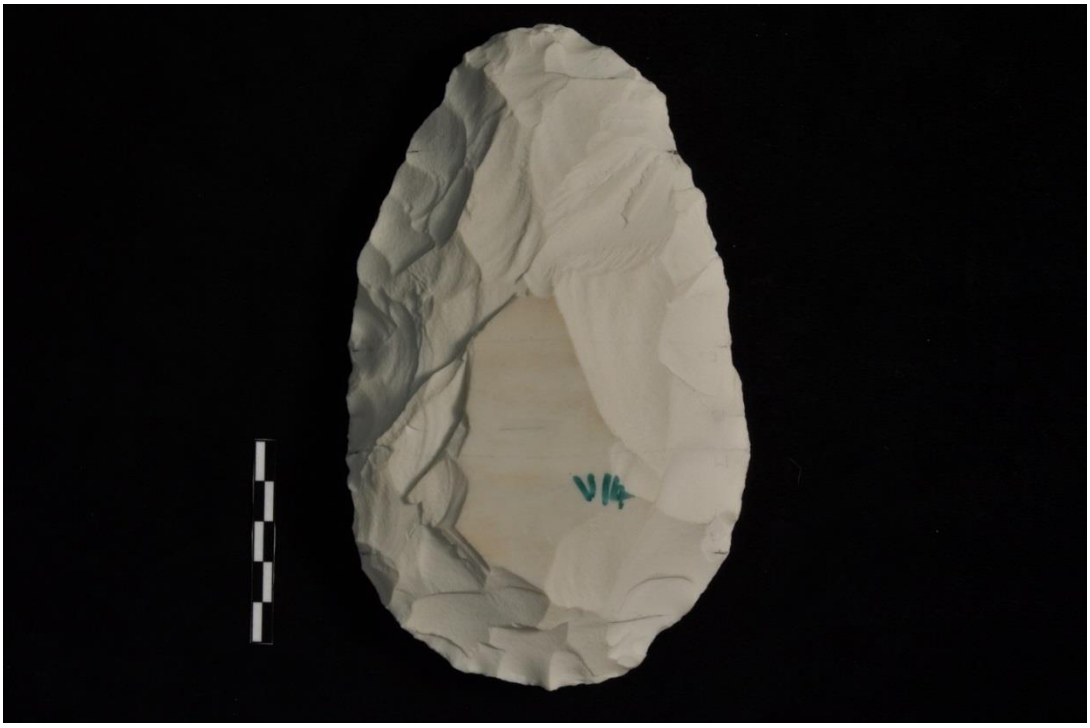
Photographs: S. Page

Knapper 5 chosen form ovate handaxe



Knapper 6 chosen form ovate handaxe

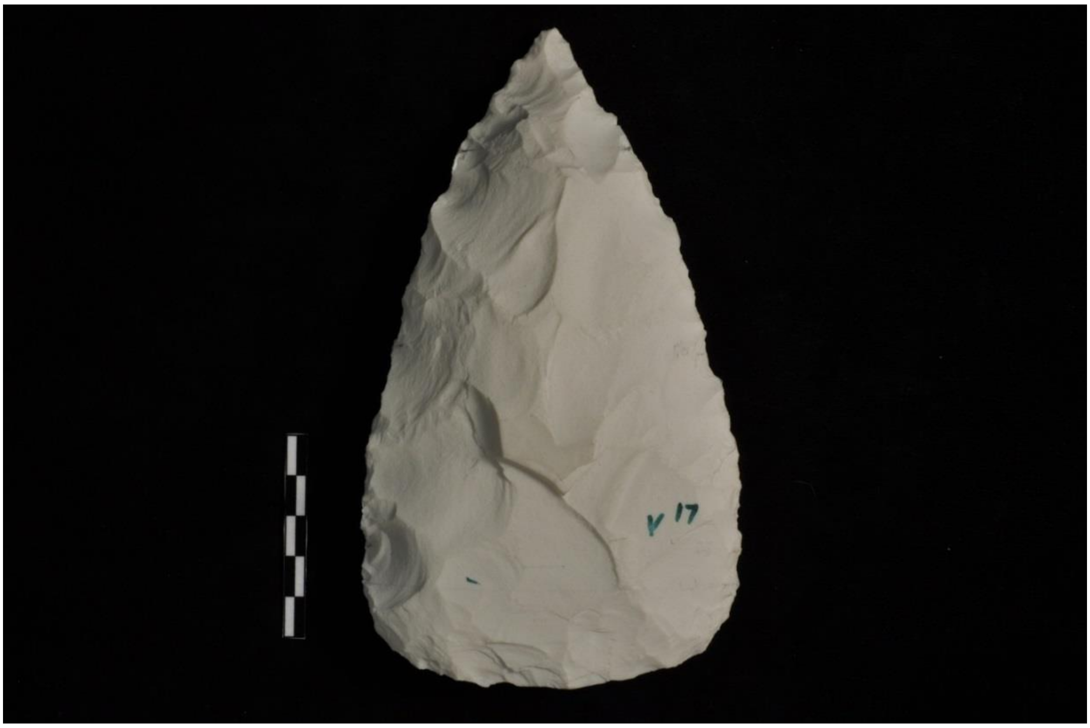
Photographs: S. Page



Knapper 7 chosen form ovate handaxe

Photograph: S. Page

Appendix 4: Experiment 2 TC2 chosen form pointed handaxes

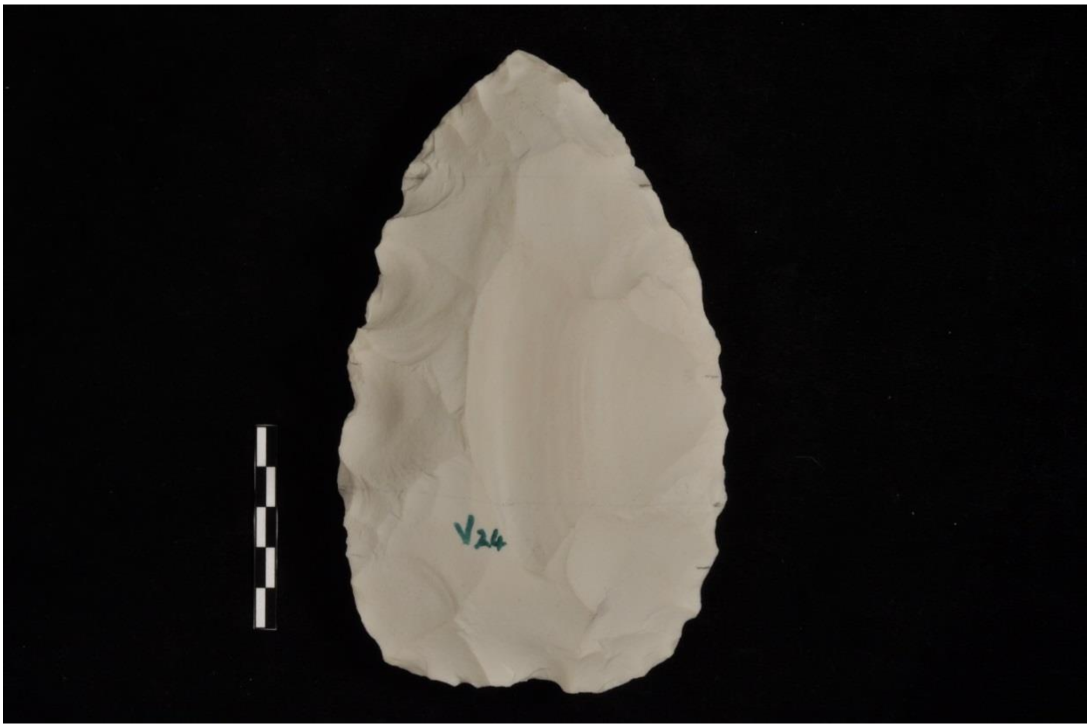


Knapper 1 chosen form pointed handaxe

Knapper 2 chosen form pointed handaxe

Photographs: S. Page

Knapper 3 chosen form pointed handaxe



Knapper 4 chosen form pointed handaxe

Photographs: S. Page

Knapper 5 chosen form pointed handaxe

Knapper 6 chosen form pointed handaxe

Photographs: S. Page

Knapper 7 chosen form pointed handaxe

Knapper 8 chosen form pointed handaxe

Photographs: S. Page

Appendix 5: Experiment 3 (TC1) chosen form pointed handaxes

Knapper 1 chosen form pointed handaxe

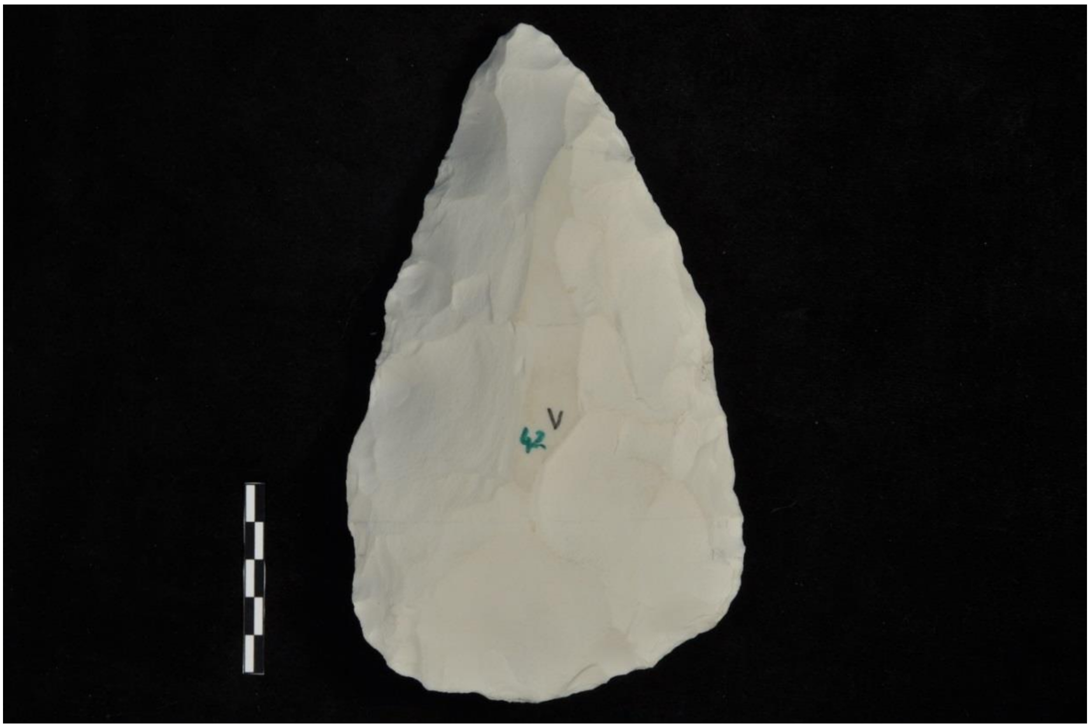
Knapper 2 chosen form pointed handaxe

Photographs: S. Page

Knapper 3 chosen form pointed handaxe

Knapper 4 chosen form pointed handaxe

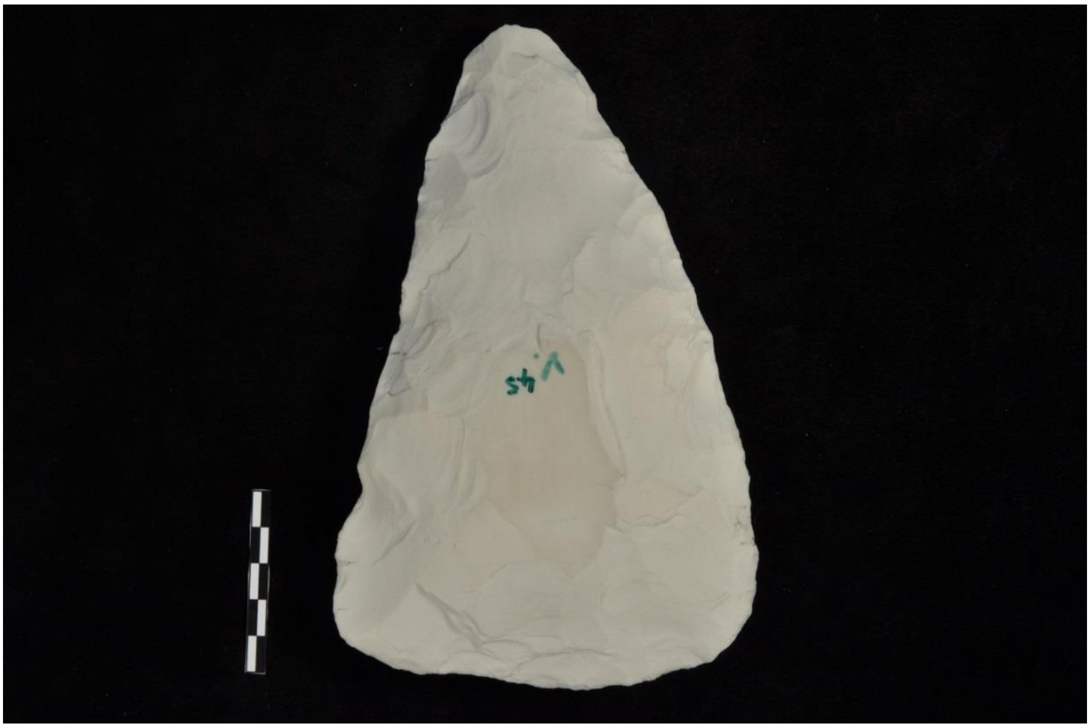
Photographs: S. Page



Knapper 5 chosen form pointed handaxe

Knapper 6 chosen form pointed handaxe

Photographs: S. Page



Knapper 7 chosen form pointed handaxe

Photograph: S. Page

Appendix 6. Experiment 4 Inter-generational Variation for Roe Refinement Ratios using Tukey's Post Hoc Test

Tests of Between-Subjects Effects

Dependent Variable: T1/L

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.002	5	.000	2.652	.036
Intercept	.402	1	.402	2585.021	.000
Generation	.002	5	.000	2.652	.036
Error	.007	42	.000		
Total	.411	48			
Corrected Total	.009	47			

Dependent Variable: Th/B

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.038	5	.008	8.681	.000
Intercept	6.078	1	6.078	6964.393	.000
Generation	.038	5	.008	8.681	.000
Error	.037	42	.001		
Total	6.153	48			
Corrected Total	.075	47			

Multiple Comparisons

Dependent Variable: Th/B
Tukey HSD

(I) Generation	(J) Generation	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	.00765	.014771	.995	-.03645	.05175
	3	-.02033	.014771	.741	-.06442	.02377
	4	-.02362	.014771	.604	-.06771	.02048
	5	-.05517*	.014771	.007	-.09927	-.01107
	6	-.07123*	.014771	.000	-.11532	-.02713
2	1	-.00765	.014771	.995	-.05175	.03645
	3	-.02798	.014771	.420	-.07207	.01612
	4	-.03127	.014771	.299	-.07536	.01283
	5	-.06282*	.014771	.002	-.10691	-.01872
	6	-.07888*	.014771	.000	-.12297	-.03478
3	1	.02033	.014771	.741	-.02377	.06442
	2	.02798	.014771	.420	-.01612	.07207
	4	-.00329	.014771	1.000	-.04739	.04080
	5	-.03484	.014771	.194	-.07894	.00925
	6	-.05090*	.014771	.015	-.09500	-.00681
4	1	.02362	.014771	.604	-.02048	.06771
	2	.03127	.014771	.299	-.01283	.07536
	3	.00329	.014771	1.000	-.04080	.04739
	5	-.03155	.014771	.289	-.07565	.01255
	6	-.04761*	.014771	.028	-.09171	-.00351
5	1	.05517*	.014771	.007	.01107	.09927
	2	.06282*	.014771	.002	.01872	.10691
	3	.03484	.014771	.194	-.00925	.07894
	4	.03155	.014771	.289	-.01255	.07565
	6	-.01606	.014771	.884	-.06016	.02804
6	1	.07123*	.014771	.000	.02713	.11532
	2	.07888*	.014771	.000	.03478	.12297
	3	.05090*	.014771	.015	.00681	.09500
	4	.04761*	.014771	.028	.00351	.09171
	5	.01606	.014771	.884	-.02804	.06016

Based on observed means.

The error term is Mean Square(Error) = .001.

*. The mean difference is significant at the .05 level.

Multiple Comparisons

Dependent Variable: T1/L
Tukey HSD

(I) Generation	(J) Generation	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	-.00061	.006238	1.000	-.01923	.01802
	3	-.00077	.006238	1.000	-.01940	.01785
	4	-.00314	.006238	.996	-.02176	.01549
	5	-.00488	.006238	.969	-.02350	.01374
	6	-.01889*	.006238	.045	-.03751	-.00026
2	1	.00061	.006238	1.000	-.01802	.01923
	3	-.00017	.006238	1.000	-.01879	.01846
	4	-.00253	.006238	.998	-.02115	.01609
	5	-.00427	.006238	.983	-.02289	.01435
	6	-.01828	.006238	.057	-.03690	.00034
3	1	.00077	.006238	1.000	-.01785	.01940
	2	.00017	.006238	1.000	-.01846	.01879
	4	-.00236	.006238	.999	-.02099	.01626
	5	-.00410	.006238	.986	-.02273	.01452
	6	-.01811	.006238	.061	-.03674	.00051
4	1	.00314	.006238	.996	-.01549	.02176
	2	.00253	.006238	.998	-.01609	.02115
	3	.00236	.006238	.999	-.01626	.02099
	5	-.00174	.006238	1.000	-.02037	.01688
	6	-.01575	.006238	.140	-.03437	.00287
5	1	.00488	.006238	.969	-.01374	.02350
	2	.00427	.006238	.983	-.01435	.02289
	3	.00410	.006238	.986	-.01452	.02273
	4	.00174	.006238	1.000	-.01688	.02037
	6	-.01401	.006238	.239	-.03263	.00461
6	1	.01889*	.006238	.045	.00026	.03751
	2	.01828	.006238	.057	-.00034	.03690
	3	.01811	.006238	.061	-.00051	.03674
	4	.01575	.006238	.140	-.00287	.03437
	5	.01401	.006238	.239	-.00461	.03263

Based on observed means.

The error term is Mean Square(Error) = .000.

*. The mean difference is significant at the .05 level.

Appendix 7. Experiment 4 Inter-generational Variation for Roe Shape Ratios using Tukey's Post Hoc Test

Tests of Between-Subjects Effects

Dependent Variable: B/L

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.050	5	.010	6.547	.000
Intercept	12.085	1	12.085	7867.088	.000
Generation	.050	5	.010	6.547	.000
Error	.065	42	.002		
Total	12.200	48			
Corrected Total	.115	47			

Only B/L produces the significant difference required for Tukey's HSD

Tests of Between-Subjects Effects

Dependent Variable: B1/B2

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.064[a]	5	.013	2.142	.079
Intercept	11.345	1	11.345	1893.943	.000
Generation	.064	5	.013	2.142	.079
Error	.252	42	.006		
Total	11.661	48			
Corrected Total	.316	47			

Tests of Between-Subjects Effects

Dependent Variable: L1/L

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.024[a]	5	.005	1.478	.217
Intercept	2.436	1	2.436	742.775	.000
Generation	.024	5	.005	1.478	.217
Error	.138	42	.003		
Total	2.598	48			
Corrected Total	.162	47			

Multiple Comparisons

Dependent Variable: B/L
Tukey HSD

(I) Generation	(J) Generation	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	-.01319	.019597	.984	-.07169	.04531
	3	.02865	.019597	.689	-.02985	.08715
	4	.04449	.019597	.229	-.01401	.10299
	5	.08020*	.019597	.002	.02170	.13870
	6	.05916*	.019597	.046	.00066	.11766
2	1	.01319	.019597	.984	-.04531	.07169
	3	.04184	.019597	.290	-.01666	.10034
	4	.05768	.019597	.055	-.00082	.11618
	5	.09339*	.019597	.000	.03489	.15189
	6	.07235*	.019597	.008	.01384	.13085
3	1	-.02865	.019597	.689	-.08715	.02985
	2	-.04184	.019597	.290	-.10034	.01666
	4	.01584	.019597	.964	-.04266	.07434
	5	.05155	.019597	.112	-.00695	.11005
	6	.03051	.019597	.631	-.02799	.08901
4	1	-.04449	.019597	.229	-.10299	.01401
	2	-.05768	.019597	.055	-.11618	.00082
	3	-.01584	.019597	.964	-.07434	.04266
	5	.03571	.019597	.463	-.02279	.09421
	6	.01467	.019597	.974	-.04384	.07317
5	1	-.08020*	.019597	.002	-.13870	-.02170
	2	-.09339*	.019597	.000	-.15189	-.03489
	3	-.05155	.019597	.112	-.11005	.00695
	4	-.03571	.019597	.463	-.09421	.02279
	6	-.02104	.019597	.889	-.07954	.03746
6	1	-.05916*	.019597	.046	-.11766	-.00066
	2	-.07235*	.019597	.008	-.13085	-.01384
	3	-.03051	.019597	.631	-.08901	.02799
	4	-.01467	.019597	.974	-.07317	.04384
	5	.02104	.019597	.889	-.03746	.07954

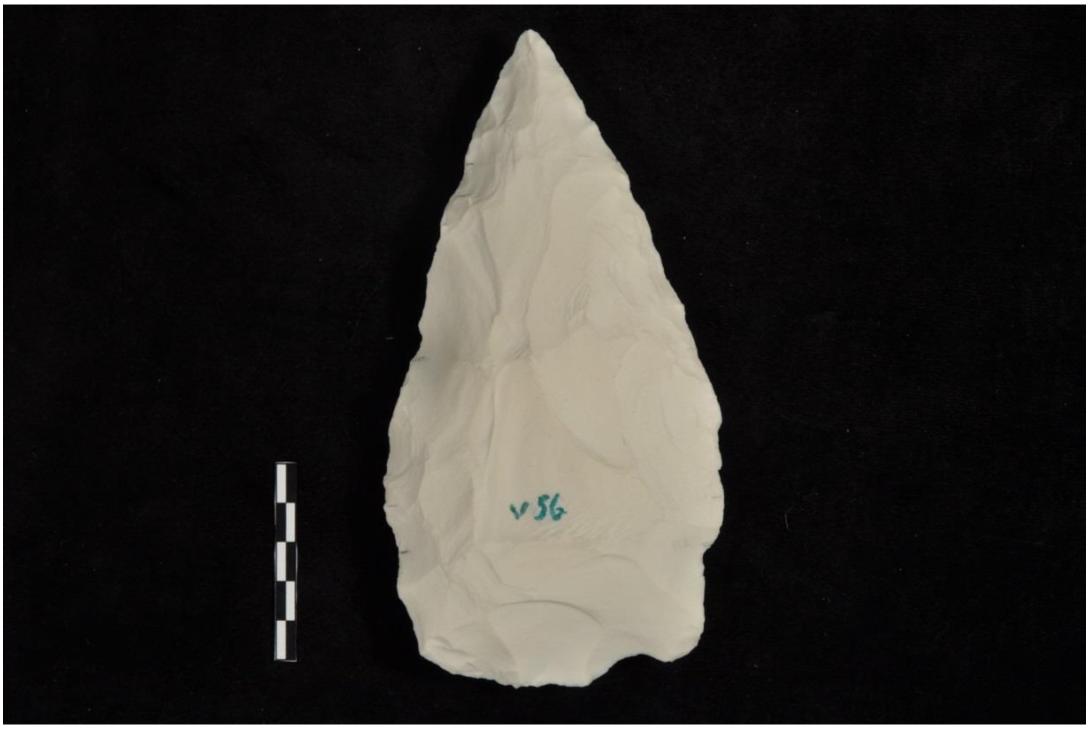
Based on observed means.

The error term is Mean Square(Error) = .002.

*. The mean difference is significant at the .05 level.

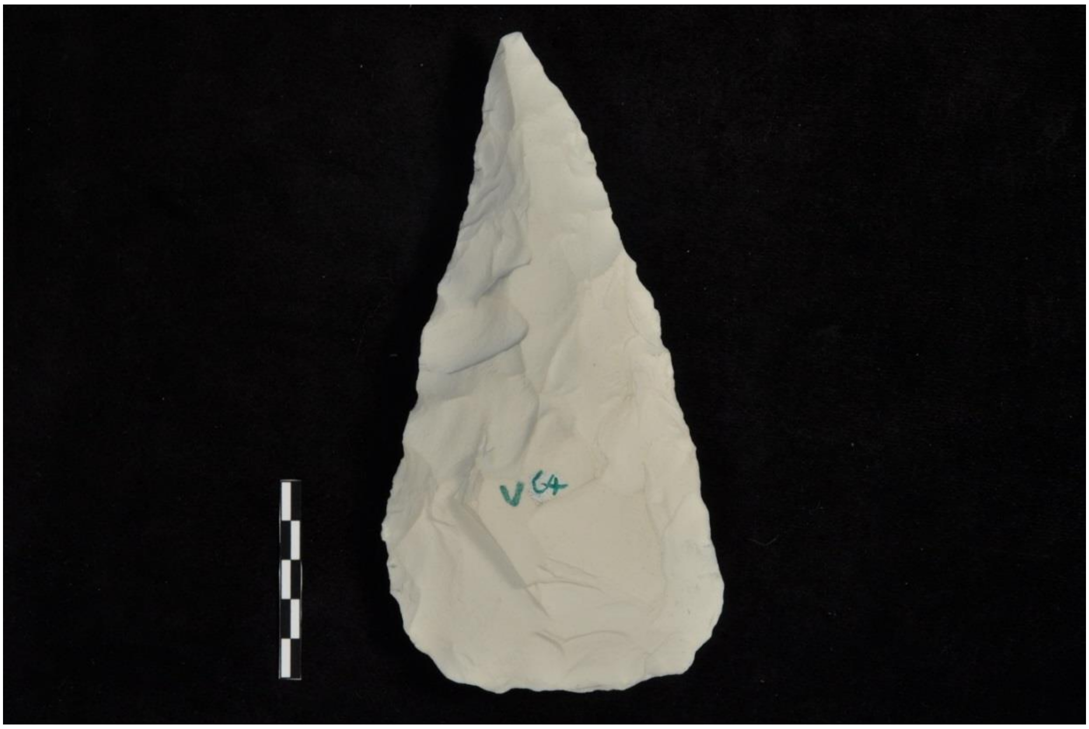
Appendix 8: Experiment 4 (TC1) chosen form pointed handaxes

Knapper 1 chosen form pointed handaxe



Knapper 2 chosen form pointed handaxe

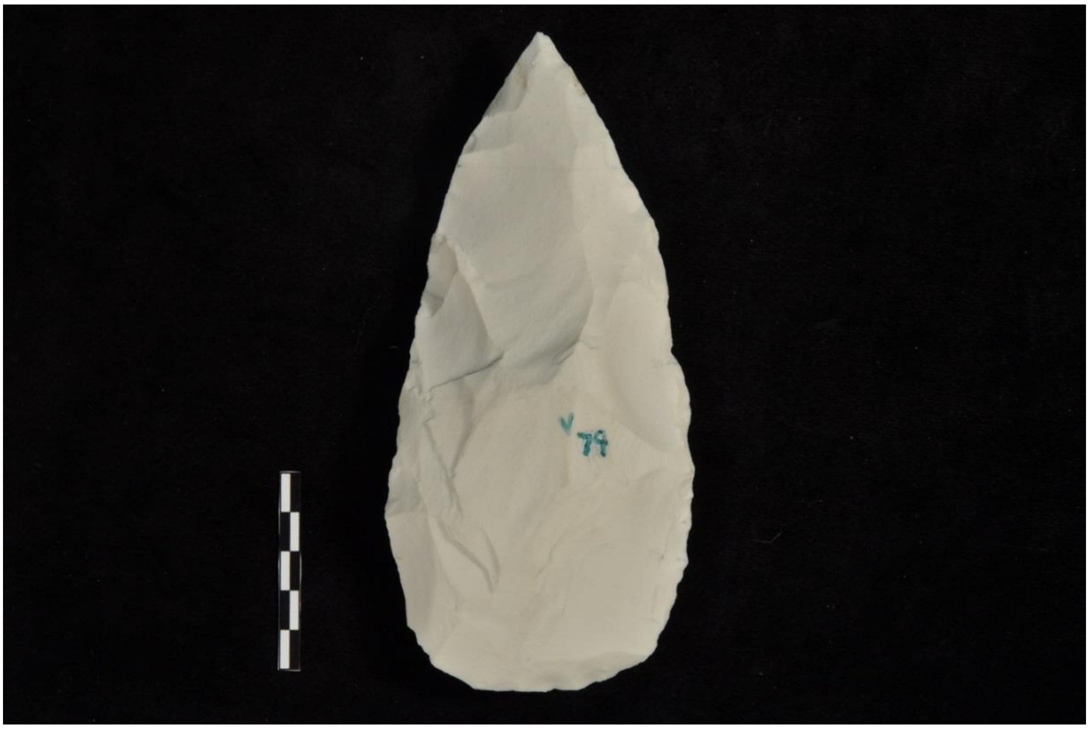
Photographs: S. Page



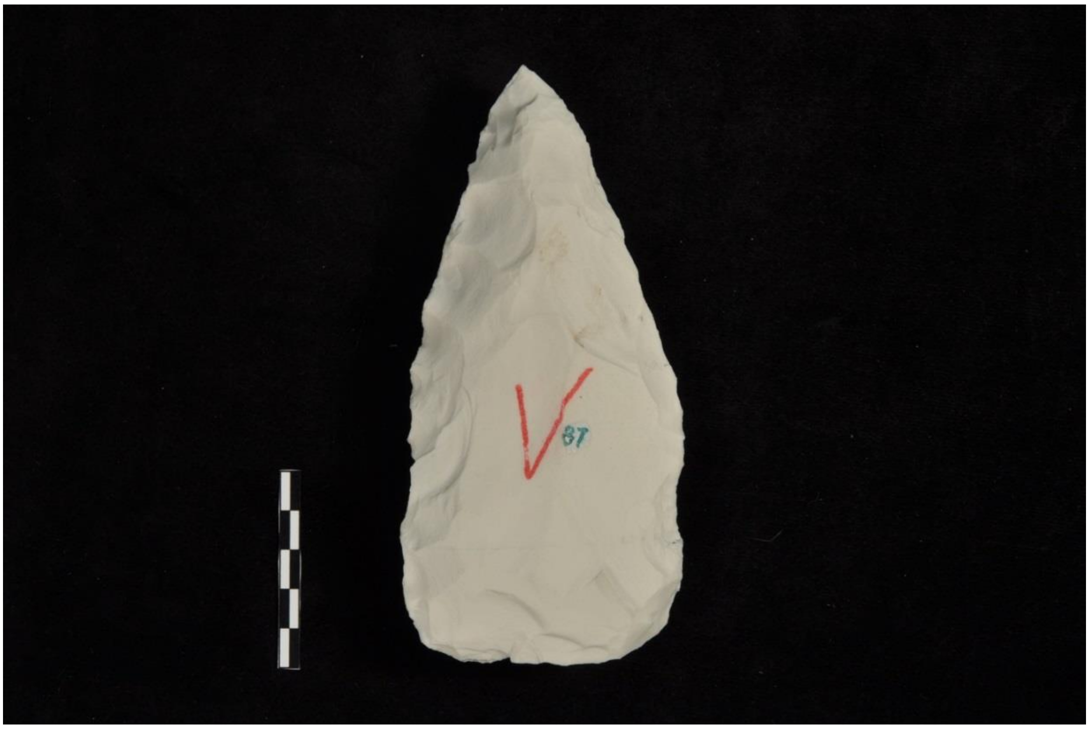
Knapper 3 chosen form pointed handaxe

Knapper 4 chosen form pointed handaxe

Photographs: S. Page



Knapper 5 chosen form pointed handaxe



Knapper 6 chosen form pointed handaxe

Photographs: S. Page

Appendix 9. Experiment 4 Inter-generational Variation for $\frac{Th}{\sqrt{ADVA}}$ using Tukey's Post Hoc Test

Dependent Variable $\frac{Th}{\sqrt{ADVA}}$

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.011	5	.002	2.433	.050
Within Groups	.037	42	.001		
Total	.047	47			

Tukey HSD Multiple Comparisons

V1	V1	MeanDifference	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	.0060231138	.0147402461	.998	.0500264165	.0379801887
	3	.0162104018	.0147402461	.879	.0602137045	.0277929007
	4	.0187111480	.0147402461	.800	.0627144506	.0252921546
	5	.0247508696	.0147402461	.553	.068754172	.0192524330
	6	.0464209136	.0147402461	.033	.0904242162	.0024176109
2	1	.0060231138	.0147402461	.998	.0379801887	.0500264165
	3	.0101872879	.014740246	.982	.0541905906	.0338160146
	4	.0126880341	.014740246	.954	.0566913367	.0313152685
	5	.0187277557	.0147402461	.799	.0627310583	.0252755469
	6	.0403977997	.0147402461	.088	.0844011024	.0036055028
3	1	.0162104018	.0147402461	.879	.0277929007	.0602137045
	2	.0101872879	.0147402461	.982	.0338160146	.0541905906
	4	.0025007461	.0147402461	1.000	.0465040487	.041502556
	5	.0085404677	.0147402461	.992	.0525437704	.0354628348
	6	.0302105117	.0147402461	.333	.0742138144	.0137927908
4	1	.0187111480	.0147402461	.800	.0252921546	.0627144506
	2	.0126880341	.0147402461	.954	.0313152685	.0566913367
	3	.0025007461	.0147402461	1.000	.0415025565	.0465040487
	5	.0060397216	.0147402461	.998	.0500430242	.0379635810
	6	.0277097656	.0147402461	.428	.0717130682	.0162935370
5	1	.0247508696	.0147402461	.553	.0192524330	.0687541722
	2	.0187277557	.0147402461	.799	.0252755469	.0627310583
	3	.0085404677	.0147402461	.992	.0354628348	.0525437704
	4	.0060397216	.0147402461	.998	.0379635810	.0500430242
	6	.0216700440	.0147402461	.685	.0656733466	.0223332586
6	1	.0464209136	.0147402461	.033	.002417610	.0904242162
	2	.0403977997	.0147402461	.088	.0036055028	.084401102
	3	.0302105117	.0147402461	.333	.013792790	.074213814
	4	.0277097656	.0147402461	.428	.0162935370	.0717130682
	5	.0216700440	.01474024614	.685	.0223332586	.0656733466

*. The mean difference is significant at the 0.05 level.

Appendix 10. Raw data files in Microsoft Excel on CD-ROM